TOWNSVILLE PORT EXPANSION PROJECT

Additional Information to the Environmental Impact Statement

APPENDIX A2

Townsville Port Expansion AEIS Hydrodynamic and Advection – Dispersion Modelling Technical Report

TOWNSVILLE PORT EXPANSION PROJECT

AECOM BMT WBM

A part of BMT in Energy and Environment

Appendix: Townsville Port Expansion AEIS Hydrodynamic and Advection-Dispersion Modelling Technical Report

Reference: R.B21057.003.03.AEIS_Modelling.docx
Date: March 2016
Confidential

Document Control Sheet

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	Title:	Appendix: Townsville Port Expansion AEIS Hydrodynamic and Advection-Dispersion Modelling Technical Report
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Synopsis:	**This technical appendix outlines and summarises hydrodynamic modelling undertaken to assess hydrodynamic and water quality impacts of the proposed Port of Townsville expansion project as part of the Additional Information for the Environmental Impact Statement.**	

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	5/2/2016	IAT		PAG	
1	26/2/2016	IAT		PAG	
2	3/3/2016	IAT		PAG	
3	30/3/2016	IAT	[signature]	PAG	[signature]

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
AECOM	PDF	PDF	PDF	PDF							
BMT WBM File	PDF	PDF	PDF	PDF							
BMT WBM Library	PDF	PDF	PDF	PDF							

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1 Introduction

1.1 Background

Evaluation of the impact of the proposed port expansion at the Port of Townsville (POT) requires a thorough understanding of the hydrodynamic and coastal processes operating within Cleveland Bay, as well as appropriate tools to support assessment of these processes. This information is necessary to optimise the port and channel design configuration from an operational and ongoing maintenance perspective as well as for consideration of construction techniques and potential adverse impacts. Wind, waves, water levels, currents and sediment transport are all interrelated and can influence the design, and positioning of the project in a number of ways.

There has been extensive data collection carried out in Cleveland Bay over many years as well as numerous studies and numerical modelling of the hydrodynamic and coastal processes.

BMT WBM (WBM) was responsible for and is in possession of the extensive oceanographic data collected in 1992 – 1993 for the modelling and monitoring of the Platypus Channel deepening and extension works at that time. WBM also undertook data collection and modelling of Cleveland and Halifax Bays associated with a proposed Nickel Ore import facility in the 1990s. This included modelling and assessment of dredging and siltation of Platypus Channel.

Other important reports reviewed as part of the current study include:

- JCU/AIMS report, "Water Circulation and Fate of Dredge Spoil, Cleveland Bay, Townsville" (1991). This study by JCU and AIMS involved oceanographic data collection and modelling of water circulation in Cleveland Bay to investigate the fate of dumped dredge material.
- GHD report, "Outer Harbour Hydrodynamic Modelling Report and Appendices" (2004). This report provides an investigation of hydrodynamic processes in the Outer Harbour and outputs of the Delft 3D model used by GHD. It also provides an overview and summary of historical data and investigations of hydrodynamic behaviour in Cleveland Bay and in the Outer Harbour area and provides a basis for assumptions about sediment transport patterns and their relationship to wind and wave processes.

As part of the Preliminary Engineering and Environmental Study (PEES) for the port expansion which was undertaken in 2008/2009 (BMT WBM, 2009), WBM was engaged to develop and employ a suite of numerical modelling tools to assess the range of potential hydrodynamic, water quality and coastal process impacts from future port expansion. WBM has continued to develop this suite of modelling tools as part of this EIS, and has assessed the potential impact of the proposed port expansion, principally using the hydrodynamic model TUFLOW FV. This technical appendix describes the model development and validation process and the results of the impact assessments.

1.2 Objectives and Purpose

Key objectives of the hydrodynamic modelling assessment of the port expansion are:

- Development of a suite of numerical modelling tools capable of simulating the hydrodynamic, wave and sedimentation processes of Cleveland Bay, in particular around Townsville Harbour;

- Assessment of the implications of the specific design configuration with respect to currents, coastal processes and sedimentation for assessment of impacts;
- Assessment of turbid plume dispersion associated with dredging for consideration of potential environmental impacts;
- Identification of any further data collection and model validation requirements necessary for detailed design and impact assessment purposes; and
- Documentation of the modelling and findings.

The modelling work presented in this technical appendix was independently peer reviewed. A letter confirming the outcomes of the peer review process is included as Appendix H2 of the EIS.

1.3 Proposed Port Configurations for Assessment

For the purposes of hydrodynamic impact assessment, the geometric configurations of the Port during the various stages of the Project have been consolidated into three scenarios as described in Table 1-1. The scenarios are described in more detail in Section 4.2. The proposed staging of the expansion and associated geometry is shown in Figure 1-1 and Figure 1-2.

Table 1-1 Hydrodynamic Impact Assessment Geometric Configurations

Label	Geometry
BASE CASE	EXISTING GEOMETRY PLUS • WIDENED WESTERN SIDE OF PLATYPUS CHANNEL CH 600 TO CH 1900.
INTERIM CASE (POST STAGE 1)	BASE CASE PLUS • WIDENED CHANNEL • INTERIM RECLAMATION AND BERTH 12
ULTIMATE CASE (POST STAGE 2 AND STAGE 3)	INTERIM CASE PLUS • DEEPENED CHANNEL (WITH EXTENSION TO THE NORTH) • FINAL RECLAMATION AND BERTHS 14, 15, 16, 17, 18

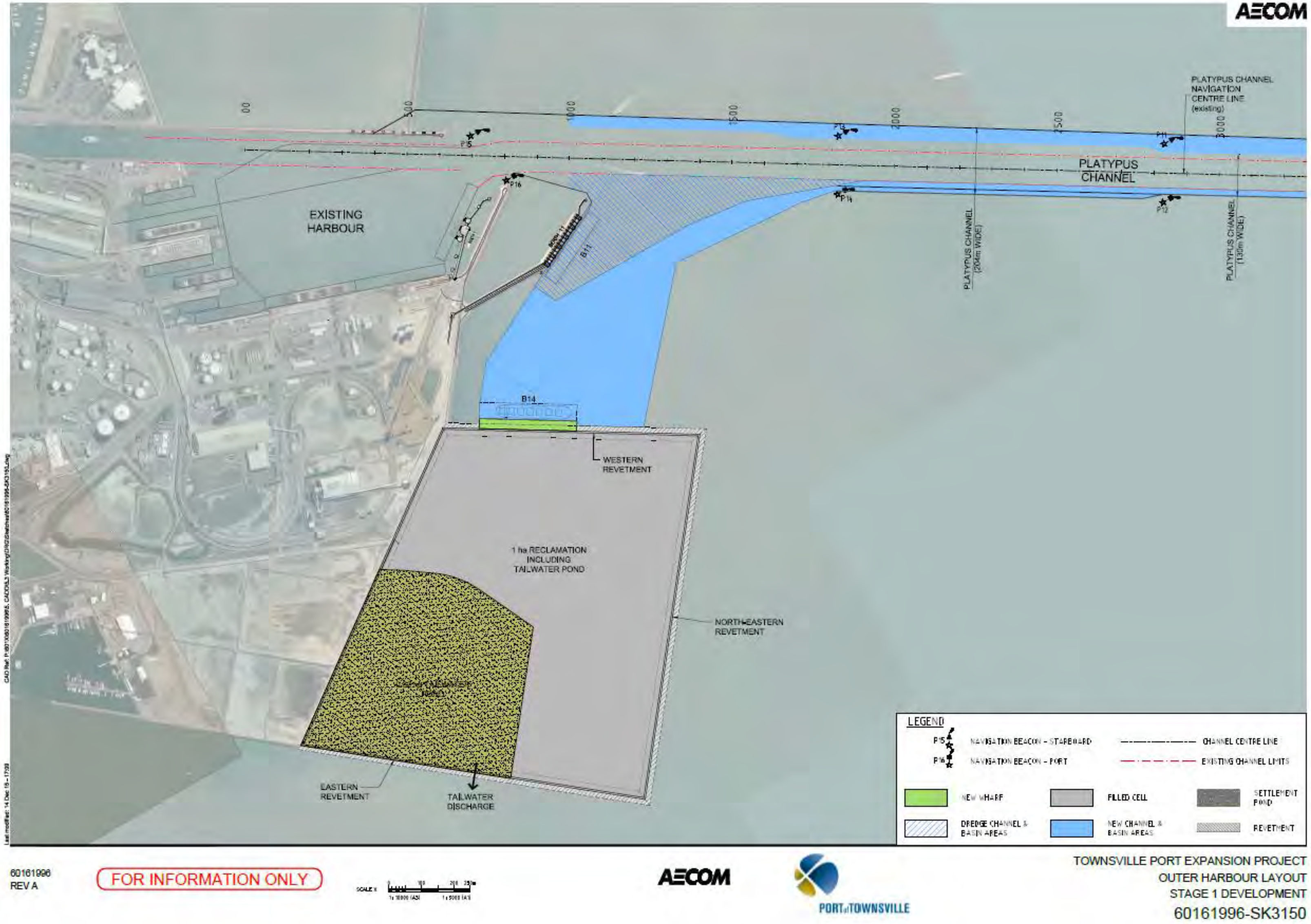


Figure 1-1 Port Expansion Staging and Geometry – Stage 1

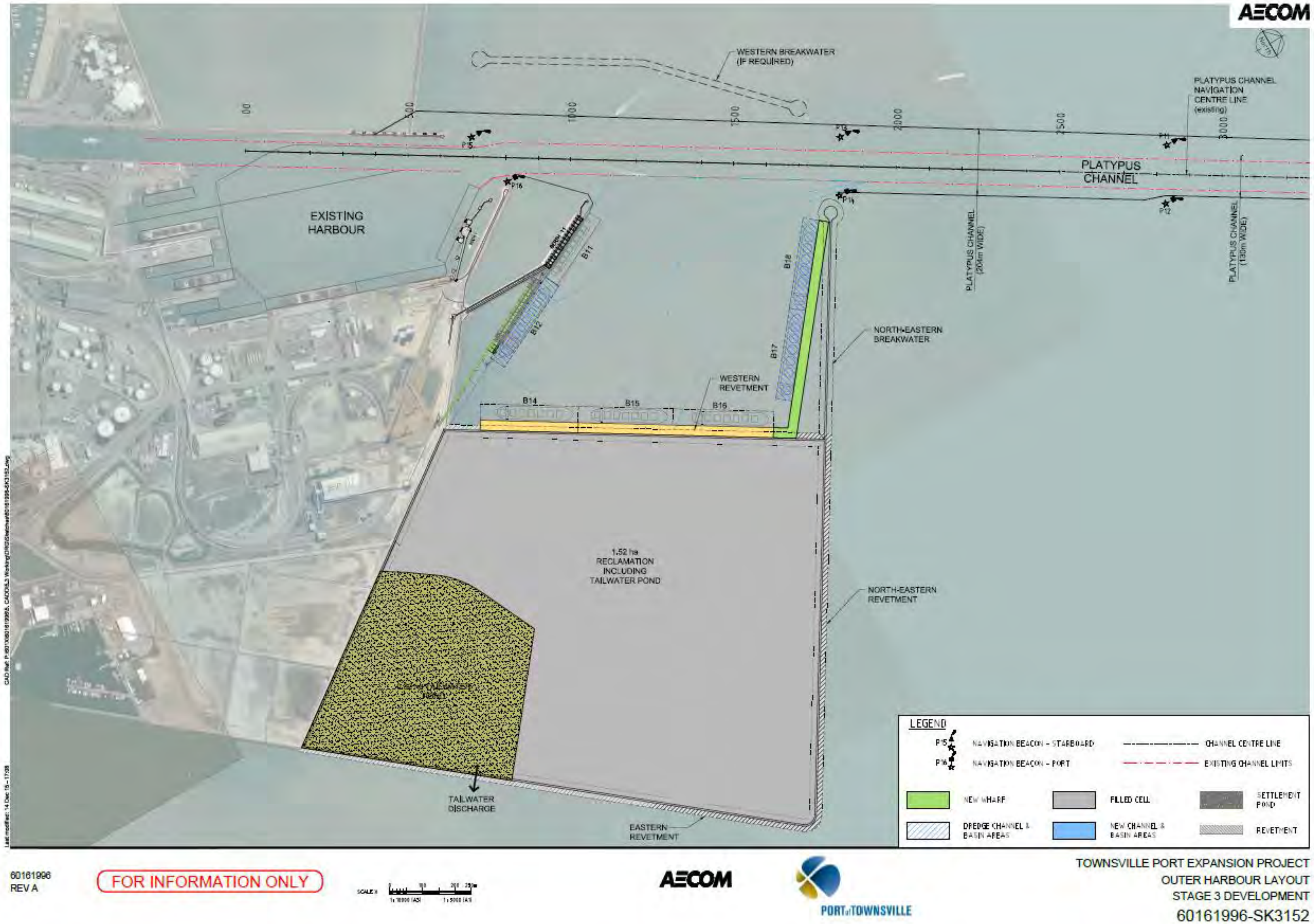


Figure 1-2 Port Expansion Staging and Geometry – Stages 2 and 3

2 Methodology and Model Development

2.1 Approach

The methodology for evaluation of hydrodynamic (HD) and advection-dispersion (AD) processes was based on three-dimensional numerical modelling. The package that was used was TUFLOW FV, which is a 3D flexible mesh hydrodynamic model that handles both hydrodynamic and advection-dispersion components. A baroclinic model configuration with density coupling from both temperature and salinity has been applied in order to represent stratification processes that occur within the Great Barrier Reef lagoon. Details of the TUFLOW FV numerical model are provided in Attachment A of this appendix.

A spectral wave model (SWAN) was also developed for assessing changes to the wave climate.

These models have been used by BMT WBM on several other major studies including:

- Gladstone Western Basin Dredging and Disposal Project (coastal studies);
- Murray River Mouth, Coorong & Lower Lakes Environmental & Morphological Modelling; and
- MetOcean and Sedimentation Study for LNG Import Terminal, Pipavav Port, India.

The modelling framework offers the ability to simulate hydrodynamics, sediment resuspension, transport and deposition and dissolved pollutant transport, and is well suited to the needs of this study.

One advantage of employing a flexible mesh model is its ability to adjust the spatial resolution of the computational network, and in particular, to increase resolution in areas of specific interest to the study. In the current study, these areas include the proposed works sites, and the existing infrastructure in the immediate vicinity, such as breakwaters and berths. The flexible mesh has been constructed to resolve these structures, with resolution also being commensurately reduced in areas where it was not needed, such as outside Cleveland Bay. As such, simulation times and efficiencies were not constrained by the highest resolution required.

Formal calibration of the numerical modelling was also undertaken as part of the study. Data used for calibration included Acoustic Doppler Current Profiler (ADCP) velocity and water level measurements from the Preliminary Engineering and Environmental Study (PEES) undertaken for the port expansion in 2008/2009 and two ADCP deployments in Cleveland Bay undertaken as part of this study.

2.2 Hydrodynamic Model Extent and Mesh Definition

The base hydrodynamic model network extends over an area of some 28,400 km^2, incorporating the Port of Townsville, Cleveland Bay, Halifax Bay and Bowling Green Bay. The modelled area represents a reach length of approximately 350km, extending from Abbott Point at the south-eastern extent to Lucinda in the north-west. The model extent includes the whole of the Great Barrier Reef lagoon between these points, and extends through reef passes into the Coral Sea.

There are a number of tidal waterways adjacent to the Port including the Ross River at Townsville, which are incorporated into the model. The modelling of the Ross River and Ross Creek focuses on representation of the tidal storage and exchange within the system as well as the delivery of fluvial (freshwater) flows into the model domain. Other waterways such as Crocodile Creek and Black River flow into the ocean along the modelled reach, but have not been included in the model as they are far from the area of interest. The model domain also extends south of the Burdekin River, which is a major ongoing source of fluvial discharge and suspended sediment to the Great Barrier Reef lagoon. The model is therefore capable of simulating freshwater plumes due to runoff from the Burdekin River catchment and the associated delivery of additional sediment and lagoon stratification.

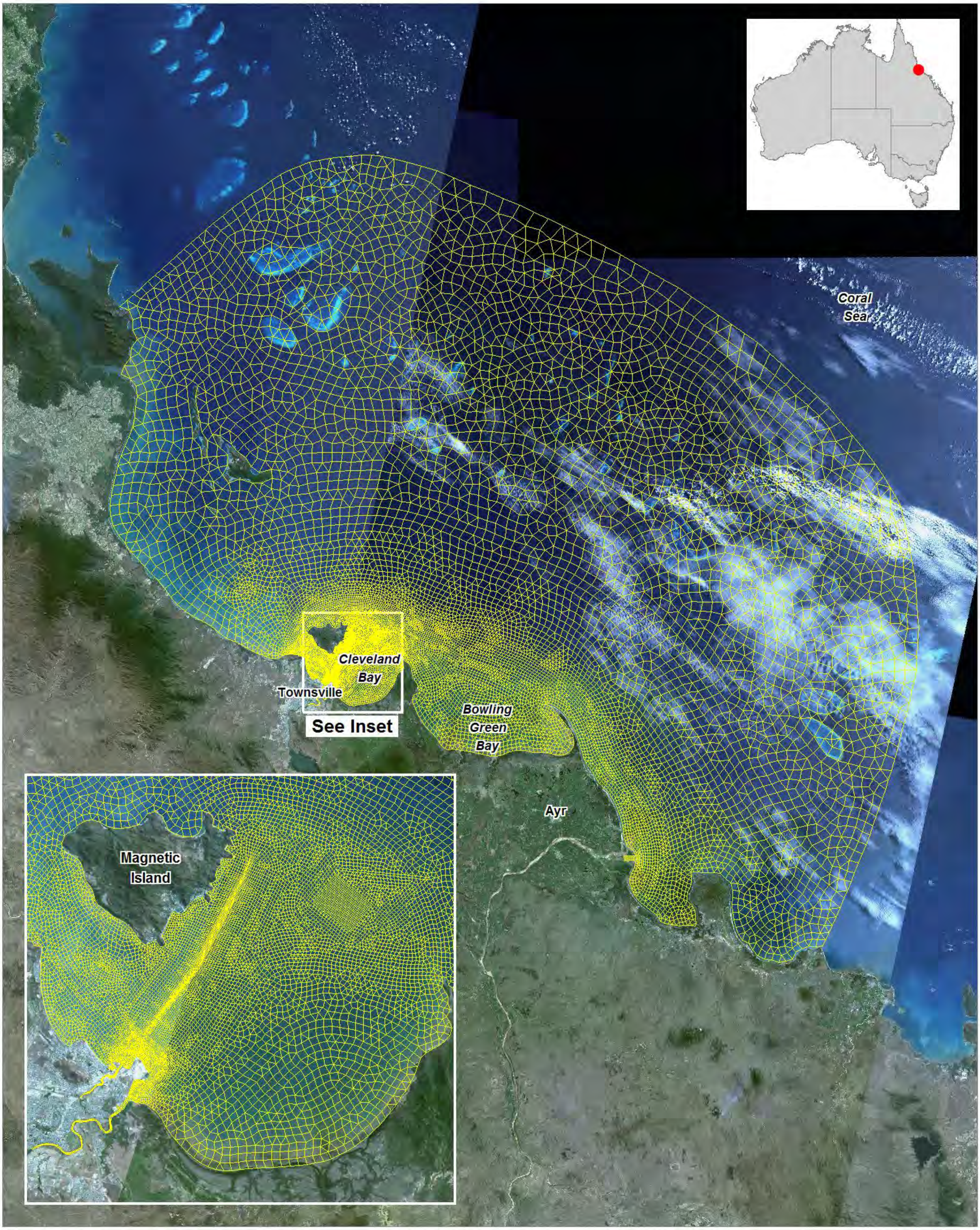
The developed model mesh for the study area is shown in Figure 2-1. In developing the model mesh, particular focus was given to a number of key areas to ensure a suitable model representation of ambient conditions. Where appropriate, the resolution of the model mesh was increased to provide a more accurate representation of local conditions. Some key areas are discussed below:

- There are numerous islands within the study area (e.g. Magnetic Is., Herald Is., Great Palm Is.), which can have an influence on flow distribution. Local adjustment of the mesh resolution has been undertaken to define the land boundaries, and the adjacent flow channels around the islands, which are typically characterised by rapid changes in bed elevation.
- Ross Creek flows into the Port of Townsville harbour. The model has been extended for approximately 3.5 km upstream of the Port in order to adequately define the tidal storage and simulate the tidal flux through the harbour.
- The Ross River is a major waterway which discharges into Cleveland Bay immediately to the south-east of the Port of Townsville facilities. The model has been extended for approximately 10 km upstream of the river mouth. This provides the opportunity to adequately define the tidal storage within the river system and simulate the tidal flux.
- The resolution of the mesh has been adapted to represent in detail the Platypus Channel out from Townsville to the sea, as well as the Port in the immediate vicinity of the Ross River confluence in order to enhance the representation of local (potentially complex) hydraulic conditions.
- The domain coverage extends well beyond Cleveland Bay into the Great Barrier Reef lagoon and includes the Burdekin River, which is the major fluvial source into the study area. The Burdekin is an important driver of hydrodynamics through the introduction fresh water and of regional morphology through its supply of ‘new’ sediments into the nearshore region.
- The existing Townsville Port Dredge Material Placement Area (DMPA) has been refined to a typical mesh dimension of approximately 100 metres to allow for accurate modelling of maintenance dredging activity.

2.3 Advection Dispersion Modelling

A system for modelling the advection and dispersion of a sediment plume produced during dredging has been developed as part of this study using the cohesive sediment module of TUFLOW FV coupled with the 3D hydrodynamic model.

To accurately capture advection and dispersion, the model requires input of dispersion coefficients and sediment characteristics. These inputs determine the resultant spread of fluid and suspended matter throughout the model domain. The choice of dredge plume source terms, dispersion coefficients, particle size distributions and settling velocities is discussed in Section 3.



Title:

Port of Townsville TUFLOW FV Model Mesh

Figure: 2-1

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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0 5 10km
Scale - Inset

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Scale - Main Map

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2.4 SWAN Wave Models

A spectral wave model for Cleveland Bay was established to assess the wave climate in the context of the proposed development and for coupling with the hydrodynamic model.

The SWAN (Delft University of Technology, 2006) numerical model was used for this purpose. SWAN is a third-generation spectral wave model, which is capable of simulating the generation of waves by wind, dissipation by whitecapping, depth-induced wave breaking, bottom friction and wave-wave interactions in both deep and shallow water. SWAN simulates wave/swell propagation in two-dimensions, including shoaling and refraction due to spatial variations in bathymetry and currents. This is a global industry standard modelling package that has been applied with reliable results to many such investigations worldwide.

A regional model covering a large section of the Great Barrier Reef lagoon and Coral Sea was established and wind boundary conditions were extracted from global NCEP model reanalyses. Wave propagation to the immediate vicinity of the Port has been assessed by establishing a nested sub-model over the section of the TUFLOW FV model within the Great Barrier Reef lagoon. The wind boundary conditions for the nested model were the same as those developed for the TUFLOW FV hydrodynamic model, as described in Section 2.7.

The SWAN model domains are shown in Figure 2-2.

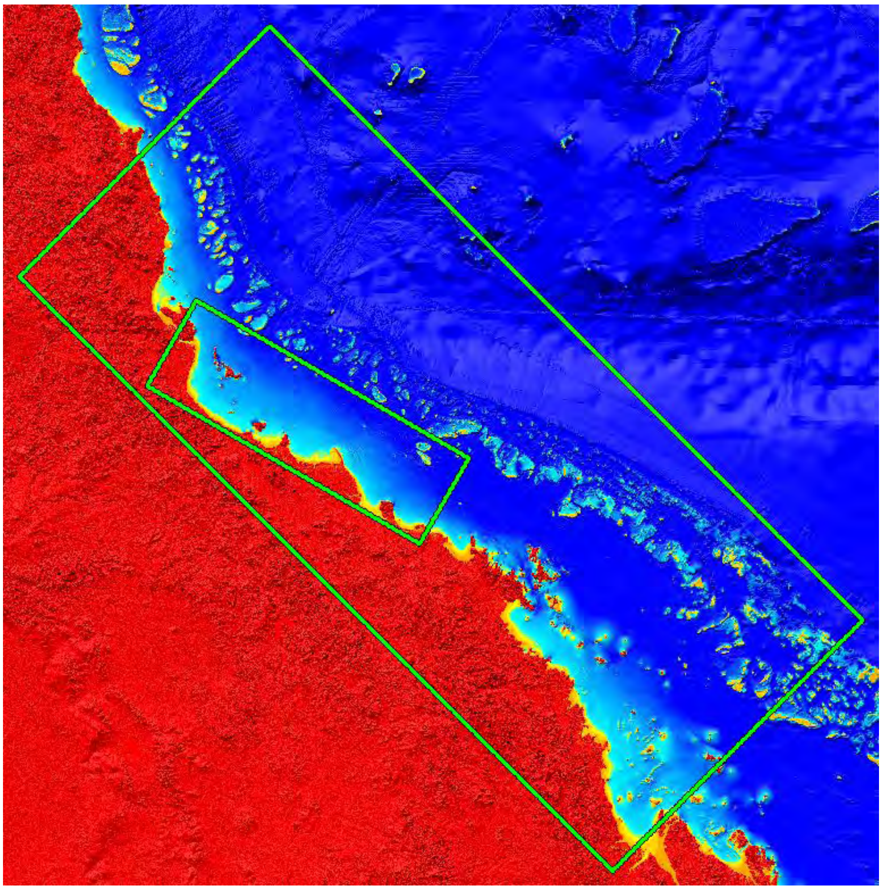


Figure 2-2 Regional and Nested SWAN Domains

2.5 Bathymetry

Hydrographic (bathymetric) data for both the hydrodynamic and wave models was sourced from the following:

- Local hydrographic survey data supplied by Port of Townsville;
- Bathymetric data of Cleveland Bay and the Great Barrier Reef Lagoon from external sources;
- Navigation charts (AUS 256) covering Cleveland Bay, Ross River and Ross Creek;
- Geoscience Australia Australian Waters Digital Elevation Model (250m grid); and
- Project 3DGBR: a high-resolution depth model for the Great Barrier Reef and Coral Sea (Reef and Rainforest Research Centre, 2010).

All these were converted to metres above Australian Height Datum (mAHD).

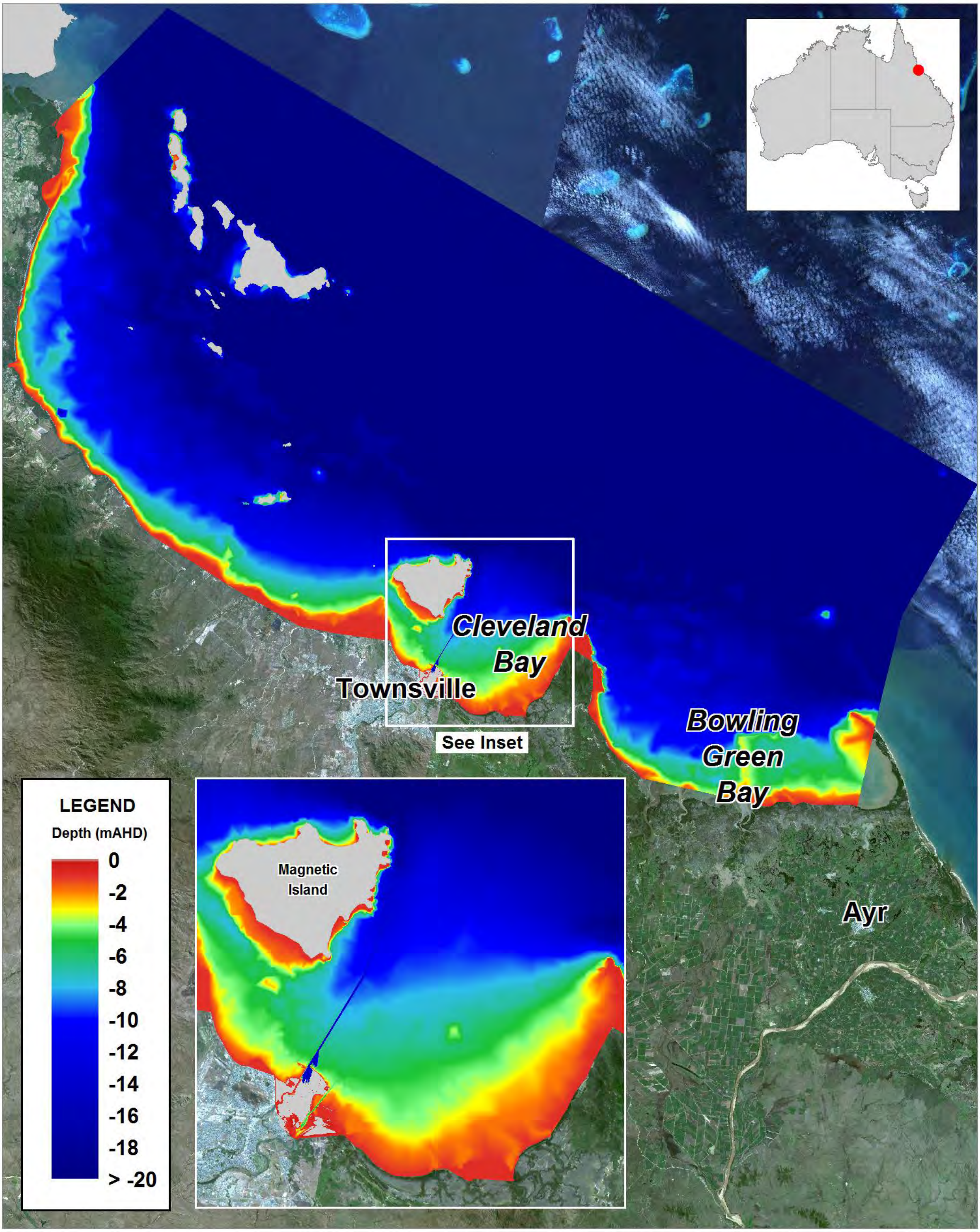
The digital elevation model of the study area as derived from the various survey components is shown in Figure 2-3.

In developing the hydrodynamic model, consideration was given to the underlying bathymetry in defining the mesh configuration. For example, model resolution was enhanced at locations of rapidly varying bathymetry or expected high velocity/flow regions based on main channel definition.

A point inspection of the DEM was used to define the bed level at the model mesh nodes located at the vertices of the individual elements of the mesh.

2.6 Tidal Boundary Conditions

The developed model extent included an open boundary that required temporal definition of water surface elevations. This boundary is shown in Figure 2-1. Due to the large extent of the model domain, tidal elevations vary spatially and temporally along the length of the boundary. Tidal data along these boundaries was extracted from a BMT WBM calibrated tide model of the Great Barrier Reef lagoon and Coral Sea, the spatial extent of which is shown in Figure 2-4. The regional tide model boundary conditions were forced by tidal constituents supplied by the Bureau of Meteorology, National Tide Centre.



Title:
Bathymetry of Model Area

Figure: 2-3

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N

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Scale - Inset

0 15 30km
Scale - Main Map

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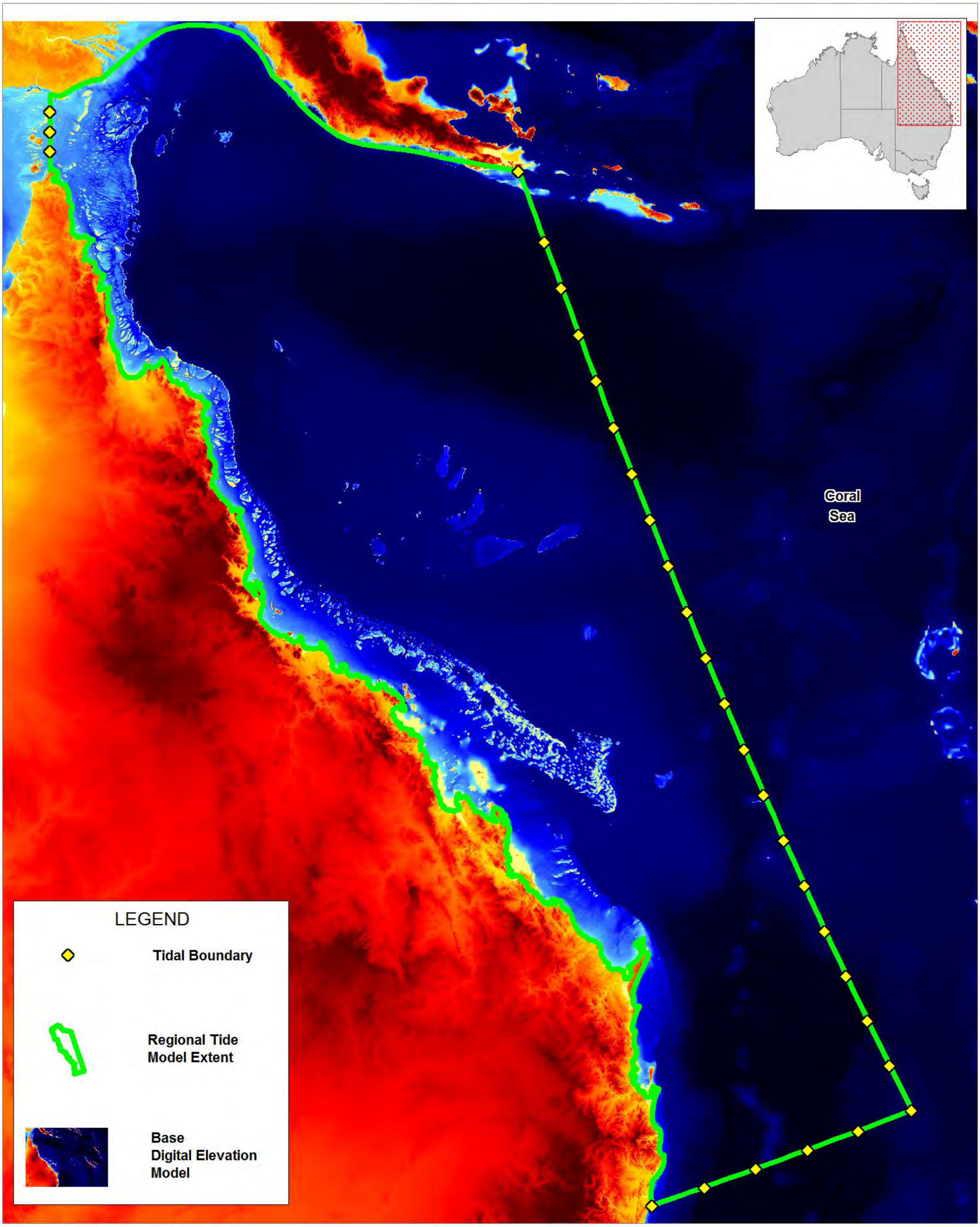

Title:

Regional Tide Model Extent

Figure: 2-4

Rev: A

N

0 200 400km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

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2.7 Salinity and Temperature Boundary Conditions

The model calibration process confirmed that 3D temperature and salinity stratification effects were significant to vertical velocity structures and hence overall circulation with Cleveland Bay. The model was therefore provided with temperature and salinity profiles at all external boundaries. These were derived from the ocean general circulation model, HYCOM (http://hycom.org/) and varied both in space (longitude, latitude and elevation) and time.

The General Ocean Turbulence Model (GOTM) was coupled with the 3D TUFLOW FV hydrodynamic model in order to simulate the vertical mixing processes in the presence of density stratification (http://www.gotm.net/).

Atmospheric heat fluxes and water column heat dynamics were simulated internally within TUFLOW FV. Boundary condition data including air temperature, long and short wave radiation, precipitation and relative humidity were obtained from global NCEP model reanalyses (NOAA, 2012). These model input fields were spatially uniform but varied in time in order to represent both seasonal and higher-frequency variations (e.g. diurnal).

The model was warmed up for a minimum period of 6 weeks prior to all calibration and impact assessments, in order to develop the internal salinity and temperature distributions contributing to density stratification.

2.8 Ocean Current Forcing

The model was provided with regional current forcing (residual water level, current magnitude and direction) at the open boundary. These were derived from the ocean general circulation model HYCOM (http://hycom.org/) and varied both in space (longitude, latitude and elevation) and time.

2.9 Wind Boundary Conditions

The Port of Townsville provided wind data (speed and direction) at ten minute intervals at the entrance to the Port (P14) for the period 2006 to 2011. A spatially interpolated wind field was constructed using additional data from the Townsville Airport, Lucinda Point and Alva Beach stations of the Bureau of Meteorology (BOM) and data from Australian Institute of Marine Science (AIMS) stations as shown in Figure 2-5. A three hour moving average of each dataset was obtained and spatially interpolated to develop a consistent and continuous dataset over the periods used for calibration and impact assessment purposes.

Figure 2-5 Wind Stations Used for the Spatially Interpolated Wind Field

2.10 Fluvial Discharge Boundary Conditions

Daily-average freshwater flows and suspended sediment loads in Ross River and Ross Creek were derived from existing catchment models developed by BMT WBM (2010).

Freshwater flows in the Burdekin River were obtained from the Department of Natural Resources and Mines via their online data delivery service (https://water-monitoring.information.qld.gov.au). The paper by Bainbridge et al (2012) which describes field measurements of the 2010-11 wet season Burdekin River plume was used to develop an approximate relationship for sediment load from the Burdekin River as a function of instantaneous flow rate as shown in Figure 2-6.

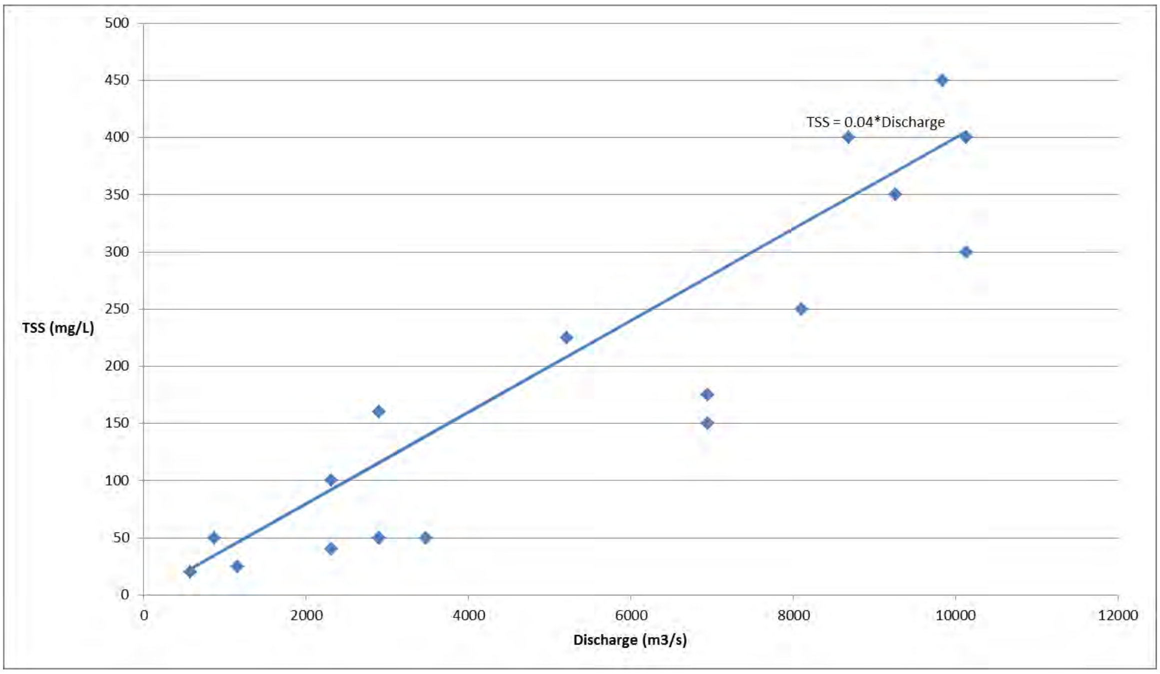


Figure 2-6 Burdekin River Sediment Rating Derived from Bainbridge et al. (2012)

Catchment inflow boundary conditions were applied as time-varying inputs extracted for the selected simulation periods and represent best-estimates of actual catchment flows at particular times rather than generalised or averaged inflows.

2.11 Material Properties

Within the TUFLOW FV model, various hydraulic properties, for example hydraulic roughness, can be assigned to groupings of model elements. This involves the specification of a spatial distribution of various material types with common properties. For example all model elements representing mangrove areas can be given a material type classification, from which it is possible to prescribe a common Nikuradse "k_s" roughness coefficient. A representation of this material classification adopted for the model is shown in Figure 2-7. This distribution was based on the bathymetry of the model, with three main areas defined as follows:

- Deep water: k_s = 0.05m;
- Reef: k_s = 1m (to represent very low conveyance across under-resolved reef structures); and
- Rocky coast: k_s = 0.5m.

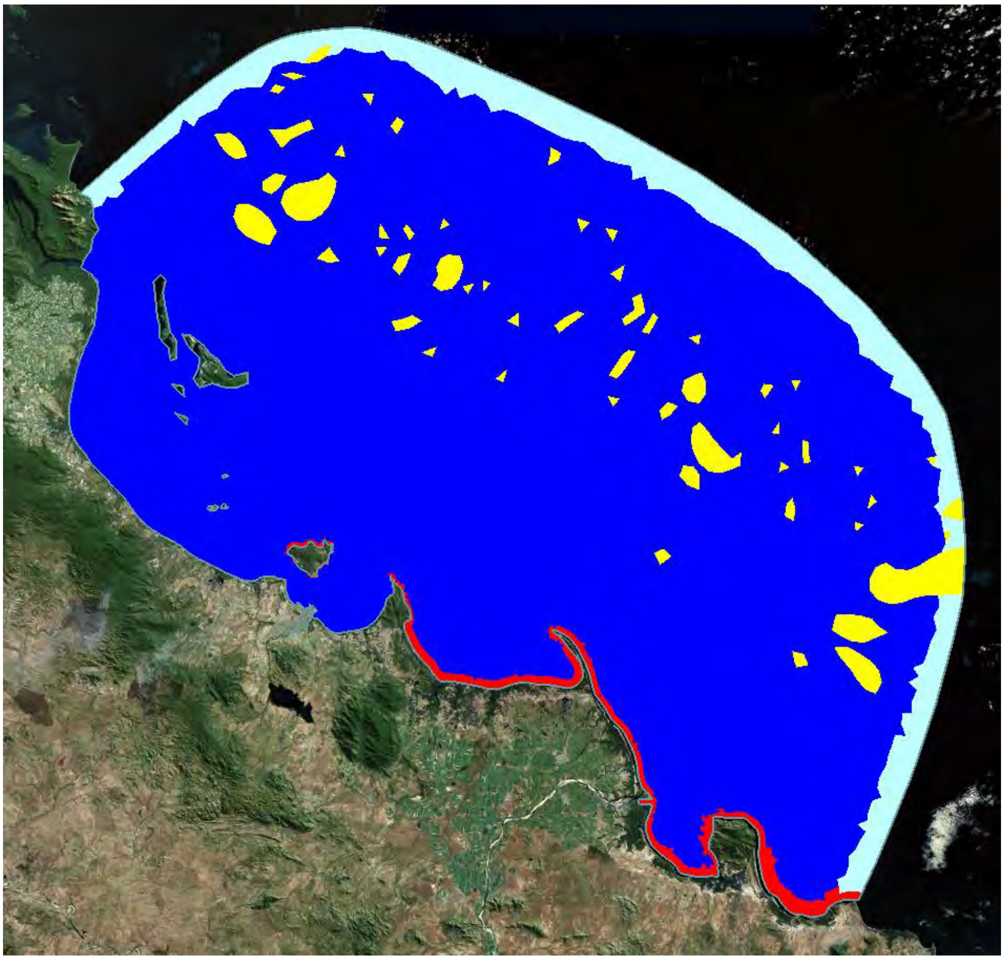


Figure 2-7 Material Distribution
Deep Water (Dark Blue), Reef (Yellow), and Rocky Coast (Red)
(Light Blue Areas Represent Boundary Regions)

2.12 Comparison of Modelling Methodology with EIS

A number of changes have been made to the numerical modelling methodology in the AEIS. Some of the changes are in order to satisfy requirements of the GBRMPA Guidelines (GBRMPA, 2012), while others have been implemented in response to feedback from EIS submissions. The most significant changes include:

- Ocean current forcing is now included on the open boundaries (Section 2.8).
- All dredge plume modelling was undertaken with both dredged and ambient sediment explicitly included. This allows for mixing of ambient and dredged sediment in the model and improves the accuracy of resuspension dynamics.
- The impact assessment methodology for dredging plumes is substantially different, and now includes a 'moving window' analysis of the change in turbidity and deposition rate percentiles due to dredging (Section 6.2.5). The collection of 12 months of ambient turbidity data has allowed impact thresholds to be derived (see the Water Quality and Ecology EIS Chapters for details).
- The model has been recalibrated for ambient sediment resuspension using the full 12 month set of water quality measurements (Section 3.4).
- A full 12 months of resuspension of dredged sediment has been analysed, rather than one month. This allows for a wider range of hydrodynamic conditions and provides a fuller description of the long term fate of dredged sediment.
- Maintenance dredging is now explicitly included in the modelling assessment and the cumulative impacts of capital and maintenance dredging are assessed.
- The modelling of the dredging program is now much more detailed with respect to the volumes of each type of material to be dredged. The available geotechnical information was used to estimate the volume of each type of material in each segment of the channel, and the source rate and particle size distribution of the dredging plume varied according to the type of material being dredged.

2.13 GBRMPA Guidelines Cross-Check

Table 2-1 provides a cross-check of the modelling approach applied in the PEP AEIS with the GBRMPA hydrodynamic modelling guidelines (GBRMPA, 2012).

Table 2-1 GBRMPA Guidelines Cross-Check Summary

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
2, 5	3D Hydrodynamic Model	All AEIS modelling assessments undertaken using 3D TUFLOW FV HD Model.	2.2
5	3D Sediment Plume Modelling	All AEIS plume modelling assessments undertaken using 3D TUFLOW FV ST Model.	2.1

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
6	Tidal forcing	Model uses spatially varying tidal forcing.	2.6
6	Wind forcing	Spatially and temporally varying wind field.	2.9
6	Wave forcing	SWAN wave model coupled with HD and ST models.	2.4
6	Ocean Current Forcing	Model simulates ocean currents. Uses HYCOM forcing at open boundaries.	2.8
6	Stratification represented	GOTM turbulence model with salinity/temperature density coupling, Burdekin River flows.	2.7
7	Hydrodynamic Calibration	HD model calibration undertaken. Independent validation undertaken.	3.1.3
7	Sediment Plume Calibration	ST model calibrated against long-term ambient turbidity datasets. Model validation performed against 2011 maintenance dredging monitoring data.	3.4 3.3
8	Wave-Current induced bed shear stress	Represented using Soulsby (1997).	3.4
8	Wave-induced mud fluidization	Wave induced resuspension mechanism included. Model calibrated/validated to suspended sediment measurements over multiple wave events.	3.4
10, 11, 12	Baseline Data	6-12 month baseline hydrodynamic datasets. 12 month baseline water quality dataset.	3.1.1
13a-c	Sediment Transport Modelling of multiple particle sizes	3 ambient sediment size fractions represented.	3.4
13d	Sediment size of material to be dredged	Additional 3 dredge sediment size fractions represented.	3.3
13e	Accurately represent ambient conditions	Model calibration/validation shows acceptable performance over a range of ambient conditions.	3.4
13e	Representative impact assessment periods.	Consideration of representativeness of impact assessment period in context of long-term climate.	4.1
13f	Represent dredging sediment sources	Source rates based on plume monitoring, advice from dredging consultant and industry experience.	6.2.3
13g	Duration of simulations	Simulations were conducted for the	6.3

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
		entire PEP dredging program.	
14c	Model horizontal resolution	Flexible mesh model (TUFLOW FV) with sufficiently high resolution in key areas of interest. Sufficiently large domain to consider long term and far field fate of sediment.	2.2
14a-b	Model vertical scheme/resolution	Hybrid z-coordinate scheme with sigma surface layers. Up to 34 layers depending on depth.	3.1.2
15	Range of impact levels assessed	Range of physical impacts assessed in modelling report. Water Quality and Marine Ecology impacts derived from model outputs as described in those respective AEIS chapters.	4 5 6
2, 3, 4, 16	Spatially based impact assessments	Model output used to derive spatial contours of change to turbidity and sedimentation rate percentiles as a result of dredging activities. Spatial Zone of Influence also derived from model output.	6.3
16	Extent, severity & Duration of impacts assessed	30 day percentiles analysis of the model output was used to derive the extent, severity and duration of turbidity impacts in the context of ambient turbidity statistics derived from baseline data. See also the Water Quality and Marine Ecology chapters.	6.2.5
9	Impact zoning scheme	Model outputs used to inform an impact zoning scheme as described in the Water Quality and Marine Ecology chapters.	AEIS Chapters
16	"Best Case" and "Worst Case" Scenarios	Expected Case and Worst Case Scenarios assessed through an ensemble modelling approach.	6.3 6.4 6.5
17	Impact thresholds	Impact thresholds derived from site specific baseline water quality data and biological criteria derived from literature. These are detailed in the Water Quality chapter.	AEIS Chapters
18	Sensitive receptors	Impact zones have been overlaid on sensitive habitat maps in the Marine Ecology chapter.	AEIS Chapters
19	Map output	Impact zone maps will be made available to GBRMPA in a suitable GIS format.	NA
20	Mid-depth and near sea	Turbidity impact maps have been	6.3

Guideline Reference/s	Guideline Requirement	How Addressed	Report Section/s
	floor turbidity impacts assessed	prepared for depth-average and nearbed.	6.4 6.5
20	Sedimentation assessed	Sedimentation rate increases due to dredging and total sedimentation attributable to dredging have been derived.	6.3 6.4 6.5
20	Timeseries outputs	Timeseries outputs of turbidity at key locations.	6.3 6.4 6.5
21	Units consistency	Water Quality modelling assessments output in turbidity units (consistent with baseline datasets). Sedimentation assessments output in rate units of $mg/cm^2/day$.	6.3 6.4 6.5
23	Independent peer review	Independent peer review completed by Doug Treloar	NA

3 Model Calibration and Validation

3.1 Hydrodynamic Model Calibration and Validation

3.1.1 Calibration and Validation Data

During PEES a bottom-mounted ADCP was deployed in Cleveland Bay in the vicinity of Platypus Channel, from the 4th September 2008 to the 11th February, 2009. The deployment location was chosen to provide representative current and wave conditions in central Cleveland Bay at a water depth of approximately 5m. This deployment provided a range of tide, wind and wave conditions during typical (but different) spring and summer periods.

In addition, the model has been validated against ADCP data collected at two other locations between October 2010 and February 2011. One ADCP was deployed near the eastern shore of Magnetic Island, and the other was deployed at the existing DMPA location. These ADCP deployment sites are shown in Figure 3-2. The data retrieved has been processed and analysed to provide the appropriate parameters necessary for model calibration and validation purposes.

Simultaneous regional data has also been collated from other sources including:

- Offshore wave data from the Waverider buoy maintained by the Department of Science, Information Technology and Innovation (DSITI); and
- Tide level data from regional tide gauges.

This data has also been used as part of the model calibration and validation process where needed.

With respect to waves, the Townsville Waverider buoy (DSITI) is located about 25 km east of the port, 5 km north of Cape Cleveland where the water depth is approximately 15m. Therefore it does not provide a direct indication of the wave climate within Cleveland Bay or at the study site. Therefore, in addition to collecting current data, the ADCPs deployed in this study also measured local wave conditions.

3.1.2 Model Parameterisation

The TUFLOW FV model was run in 3D hydrodynamic mode using a z-coordinate scheme with layer thicknesses of less than 1 m down to an elevation of -13 m AHD and 2 m or less down to an elevation of -25 m AHD. A maximum of 30 layers were resolved in the deeper sections of the model domain, with the bottom layer thickness varying according to the local depth below -25 m AHD. This high degree of vertical resolution in the top 25 m of the water column was necessary in order to simulate vertical stratification within the water column. This also allowed for detailed representation of the vertical distribution of dredge plume suspended sediment.

Salinity and temperature were simulated within the model as density-coupled scalar constituents in order to incorporate baroclinic density gradient forcing and more-importantly the effect of vertical density stratification on the water-column turbulence.

The General Ocean Turbulence Model was coupled with the hydrodynamic model for the purposes of deriving vertical turbulent mixing parameters. A 2-equation k-omega model was adopted with default parameters.

3.1.3 Hydrodynamic Model Calibration Results

The model was run in 3D baroclinic mode over two calibration periods from 1st October 2008 to 1st November 2008 and from 1st December 2010 to 1st February 2011. These periods incorporated representative spring and neap tide conditions and a range of meteorological conditions. This enabled assessment of the ability of the model to adequately represent a range of conditions and its suitability for use in impact assessments.

The calibration and validation results in terms of comparison of simulated water levels and velocities against observed data are presented in the following sections.

3.1.3.1 Water Levels

Validation plots of observed versus simulated water levels are shown in Figure 3-1 for the Townsville storm tide gauge (marked as 'Townsville Gauge' in Figure 3-2), for representative spring and neap tide conditions. Both figures show that the modelled water levels are consistent with measurements in terms of phasing and amplitude.

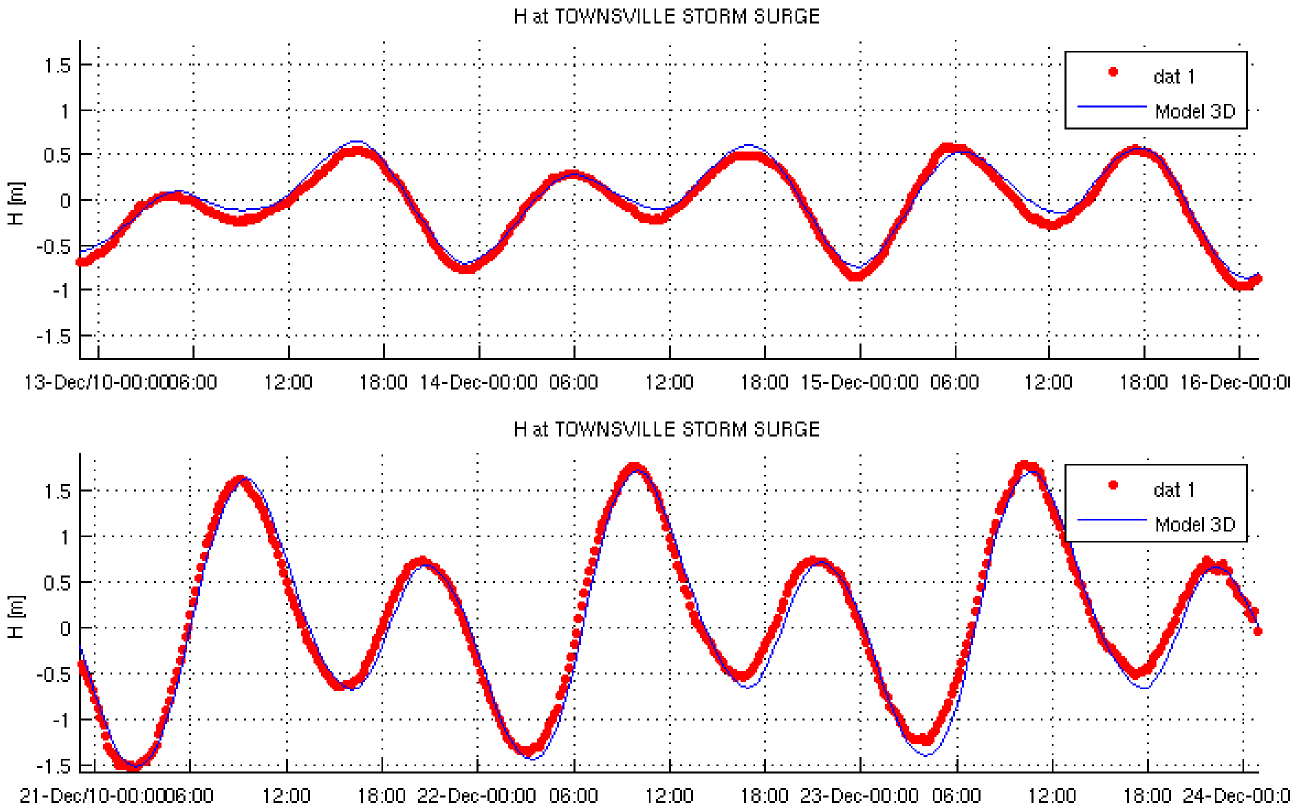


Figure 3-1 Water Level Validation – Townsville Storm Surge Gauge (2010)

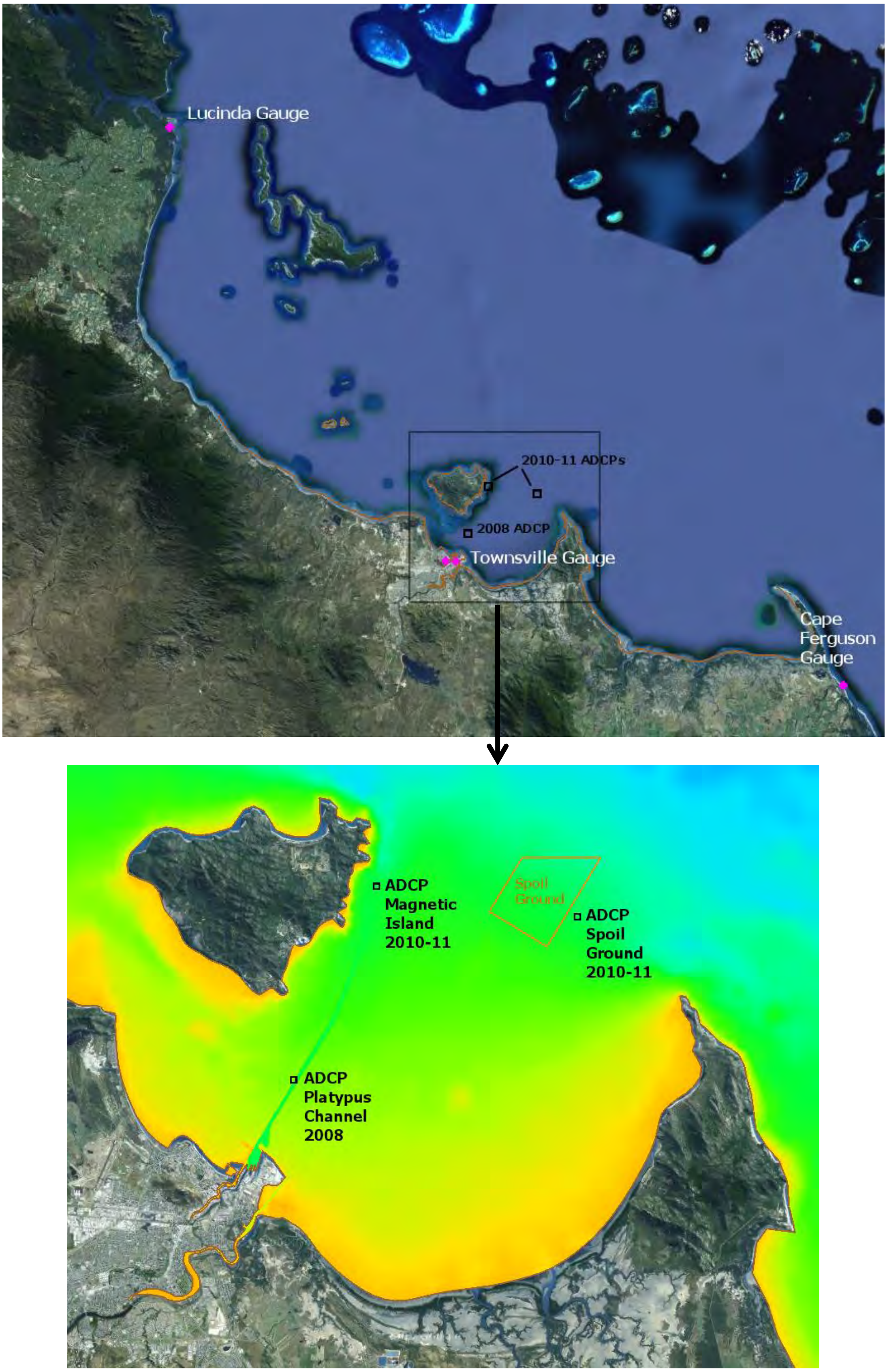


Figure 3-2 Location of Model Calibration Points

3.1.3.2 Water Temperature

A comparison of modelled temperature from the summer 2010/11 validation period with measurements from the AIMS Cape Cleveland station is shown below. Following an initial over-prediction in temperature the model can be seen to be in reasonable agreement with the measurements.

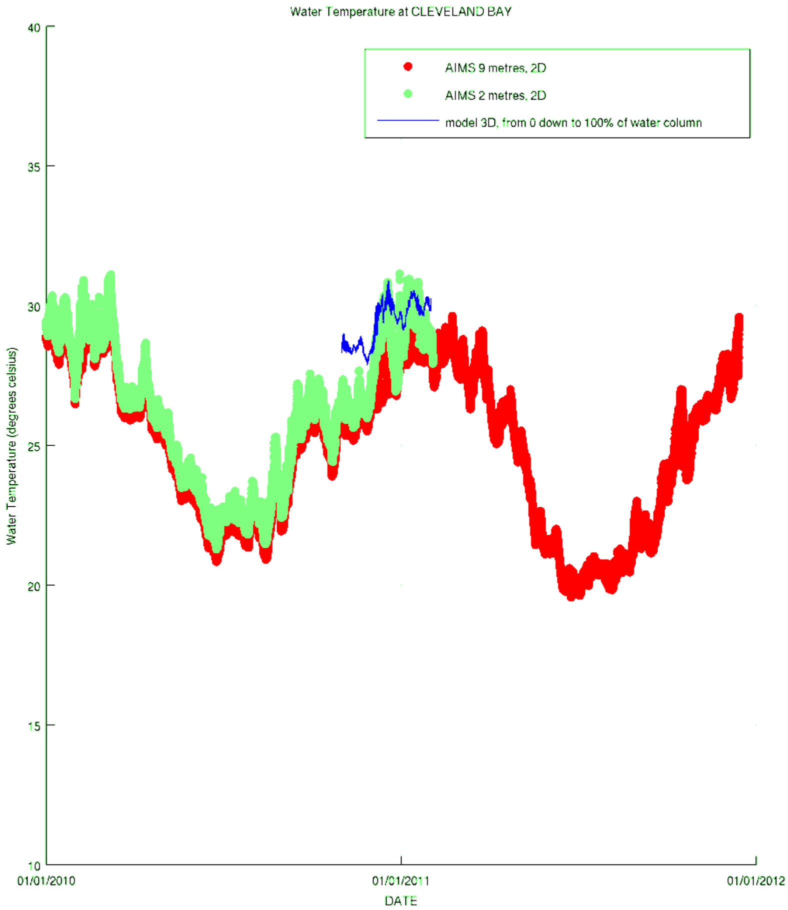


Figure 3-3 Temperature Validation – AIMS Cape Cleveland Station

3.1.3.3 Salinity

The summer of 2010/11 was one of the wettest on record for the study area and resulted in significant flood flows from the major Burdekin River catchment which discharges into the Great Barrier Reef lagoon approximately 100km south-east from Townsville. Bainbridge et al. (2012) have described a campaign of measurements focussed on the Burdekin River plume during this period, and include comparisons with a series of MODIS satellite images of the plume.

Figure 3-4 shows a surface salinity plot from the TUFLOW FV model for the 4th of January 2011 together with the MODIS satellite image from the same date (http://oceancolor.gsfc.nasa.gov/). These model results show reasonably good qualitative agreement with the plume spatial distributions which are discernible from the MODIS satellite images. The remaining surface salinity snapshots for comparison with the Bainbridge et al. Figure 3 are provided in Attachment B of this appendix.

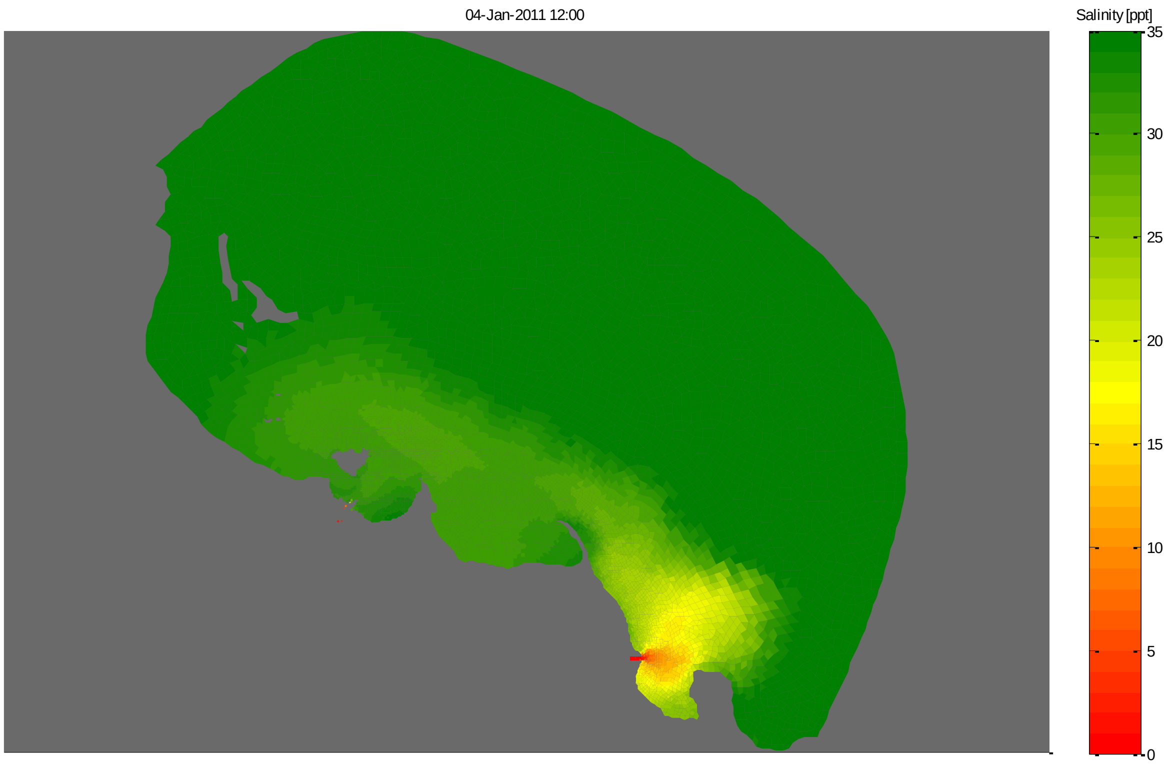


Figure 3-4 Modelled Surface Salinity on the 4th January 2011 (bottom) and the MODIS Satellite Image for the Same Date (top).

3.1.3.4 Current Velocities

Model outputs were compared against the ADCP current velocity magnitude and direction measurements (see Figure 3-2 for ADCP locations). The ADCP data was post processed to provide time series averages of the velocities in the top 50% and bottom 50% of the profile, to allow comparison with the three dimensional output of the model.

Vertical variations in current speed and direction that were indicative of stratification within the water column were sometimes observed in the measured ADCP data, particularly from the 2010-11 summer/wet season deployments. An example velocity profile measured at the DMPA ADCP is shown in Figure 3-5, and can be seen to illustrate the degree of vertical current profile variation that occurred during the significant catchment runoff events in January 2011. Also shown in this figure are the model predictions which demonstrate that the turbulence scheme is able to successfully capture these processes.

The time series model versus data comparisons are shown in Figure 3-6 to Figure 3-11. It can be seen that the velocity magnitude predicted by the TUFLOW FV model is generally within the bounds of the accuracy of the recorded data. In particular, spring tide conditions are reproduced accurately in terms of both timing and amplitude at all three ADCP locations.

Velocity directions are generally well reproduced by the model, except for the 2010 Magnetic Island data where the model sometimes misses the full rotation of the velocity vectors. Overall the model predicts the general hydrodynamic characteristics within the region of interest with sufficient detail for the purposes of this study.

During the 2010 monitoring campaign it is understood that the salinity influence from the Burdekin River flood plume may have begun to influence the DMPA and Magnetic Island monitoring sites from around the 9th December. At this time, the surface currents at the DMPA site are seen in both the data and the model predictions to “decouple” from the near-bed currents. While the agreement at the DMPA site is good the model skill at predicting the Magnetic Island ADCP current behaviour is not as good as for the preceding period.

Current roses for the top and bottom 50% of the profile at the ADCP deployment locations are presented in Figure 3-12 to Figure 3-17. The top panel is the model output, and the bottom panel is the measured ADCP data.

Agreement between the model and data for both directions and magnitudes is excellent for the 2008 data collected near the Platypus Channel.

Compared to the data at the Magnetic Island location in 2010, the model does a good job of estimating current magnitudes, but tends to overestimate the directional spread in the bottom 50% of the water column and underestimate the spread in the top 50% of the water column.

At the DMPA location, the model underestimates the directional spread in the bottom 50% of the water column and slightly underestimates velocity magnitudes in some directions. In the top 50% of the water column at the DMPA, velocity magnitudes for currents travelling towards the West are somewhat underestimated, and the predominant direction is biased slightly to the south with respect to the data.

Overall, the model performance is considered to be acceptable for the purposes of the present study.

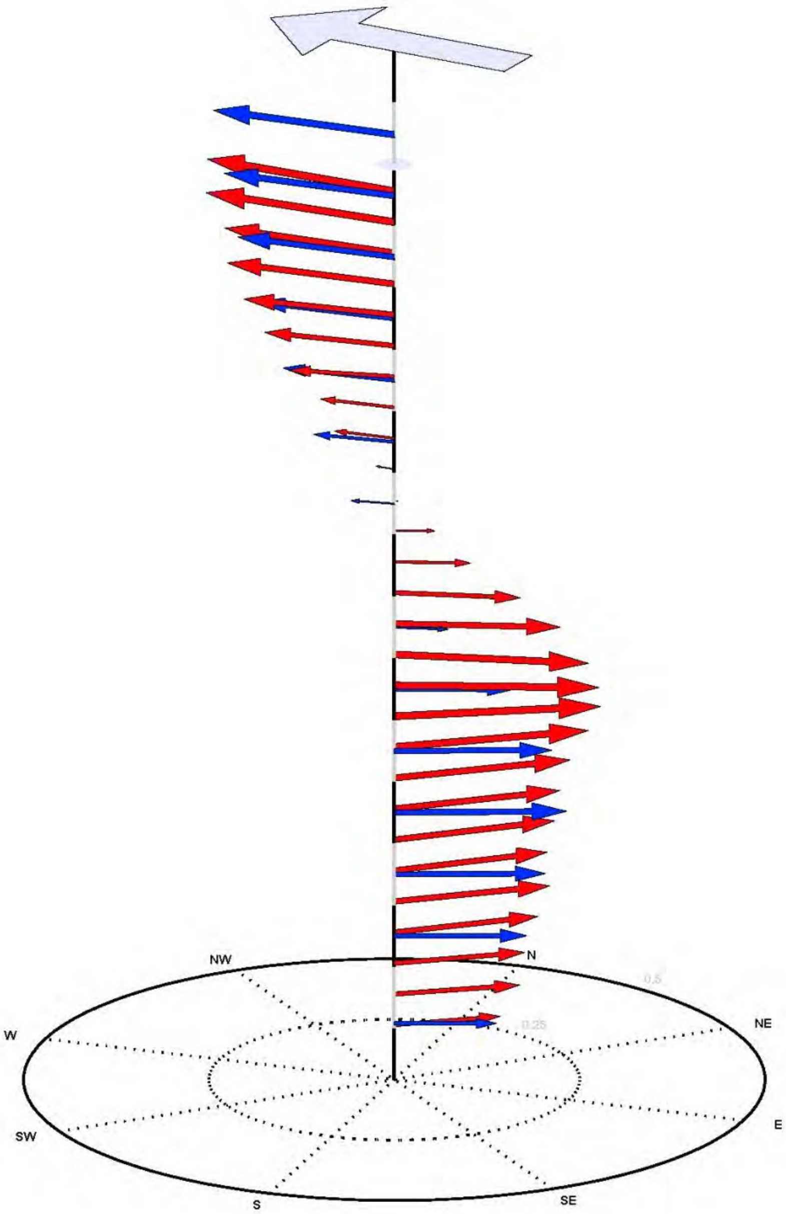


Figure 3-5 Velocity Profile at the DMPA ADCP
Blue Arrows – Model; Red Arrows – Data
The Grey Arrow at the Top of the Profile Indicates the Wind Direction

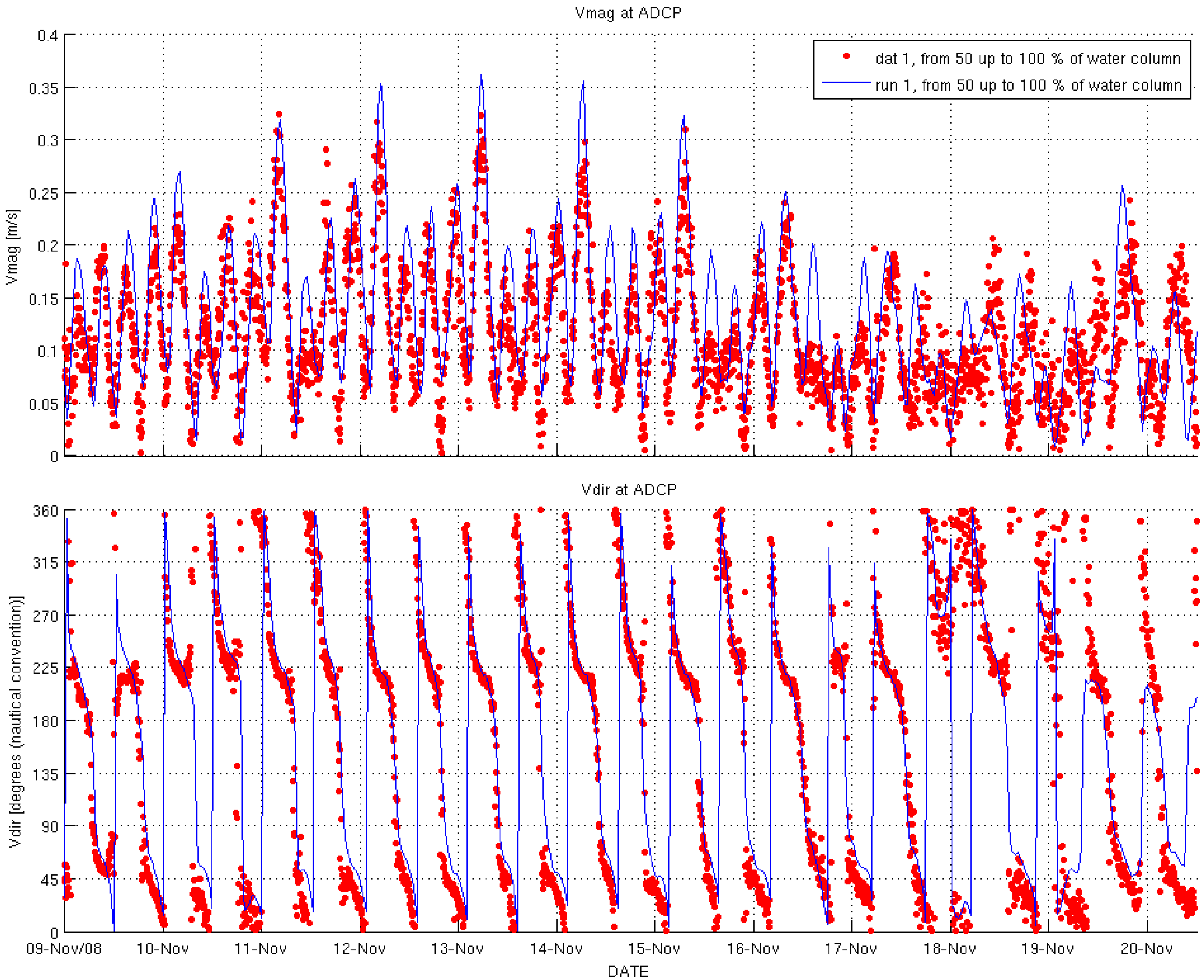


Figure 3-6 Velocity Magnitude Validation Time Series – 2008 PEES ADCP Data – Top 50%

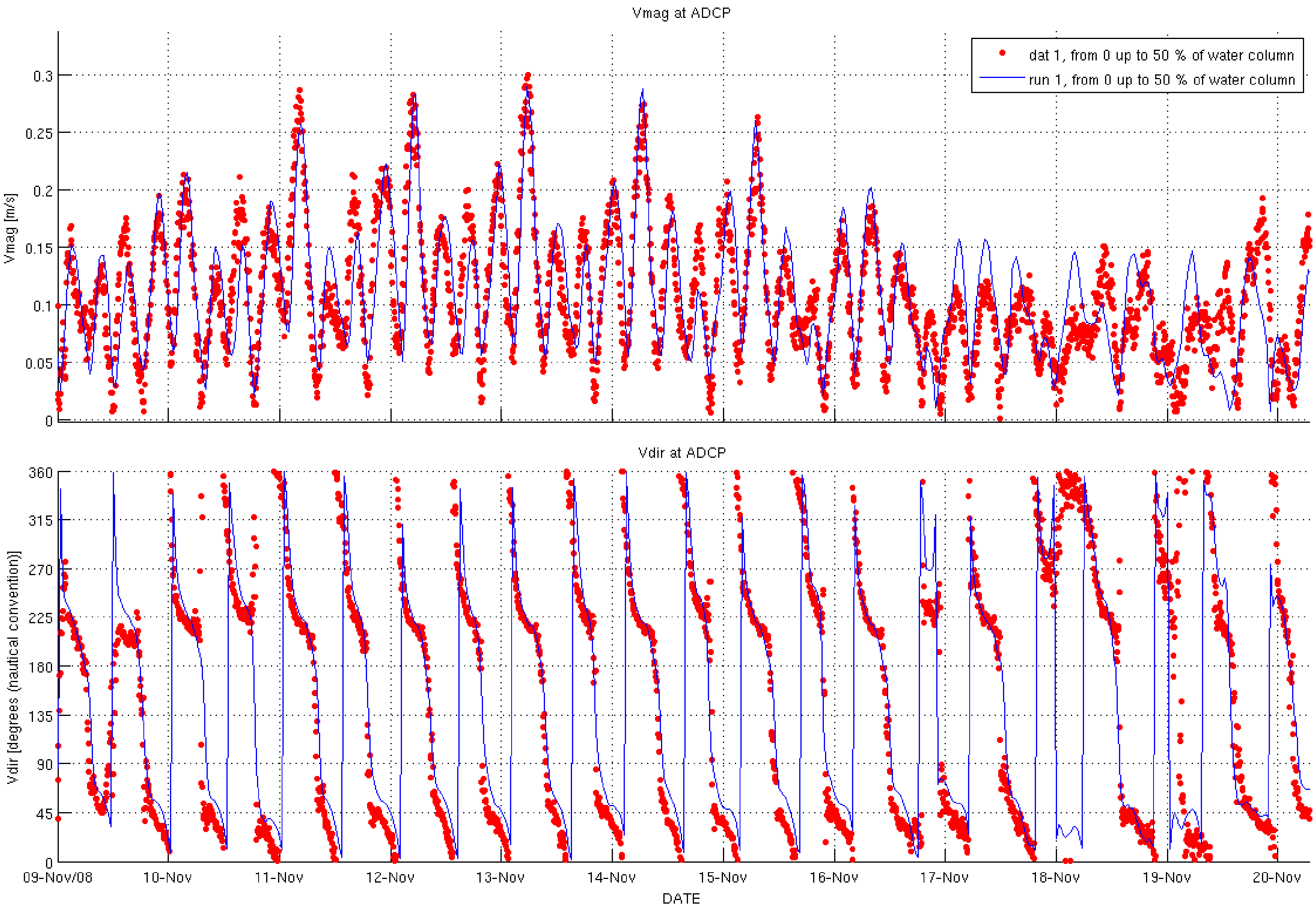


Figure 3-7 Velocity Direction Validation Time Series – 2008 PEES ADCP Data – Bottom 50%

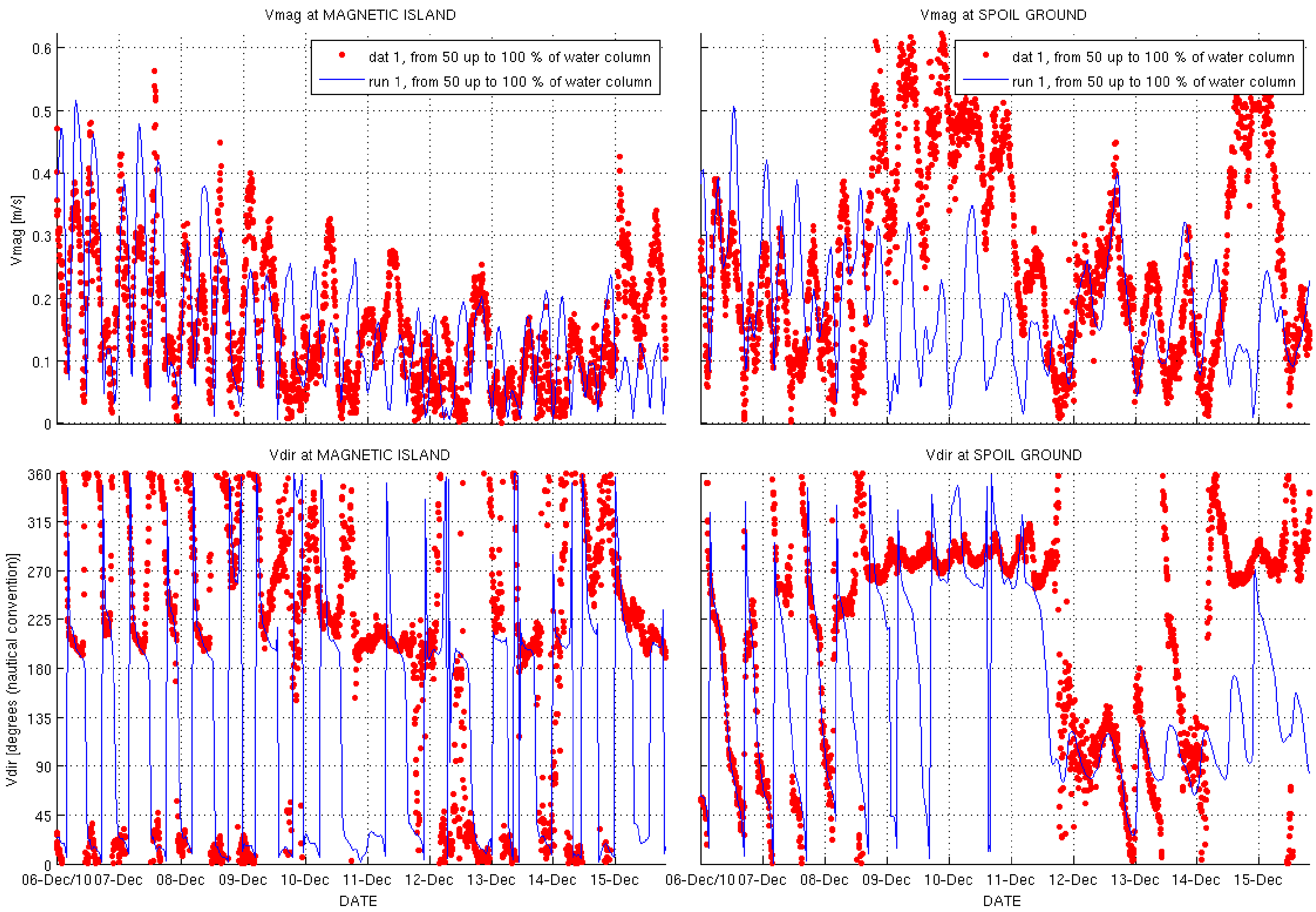


Figure 3-8 Velocity Validation Time Series – 2010 ADCP Data Top 50%, 6-16 December – Magnetic Island (Left) and DMPA (Right)

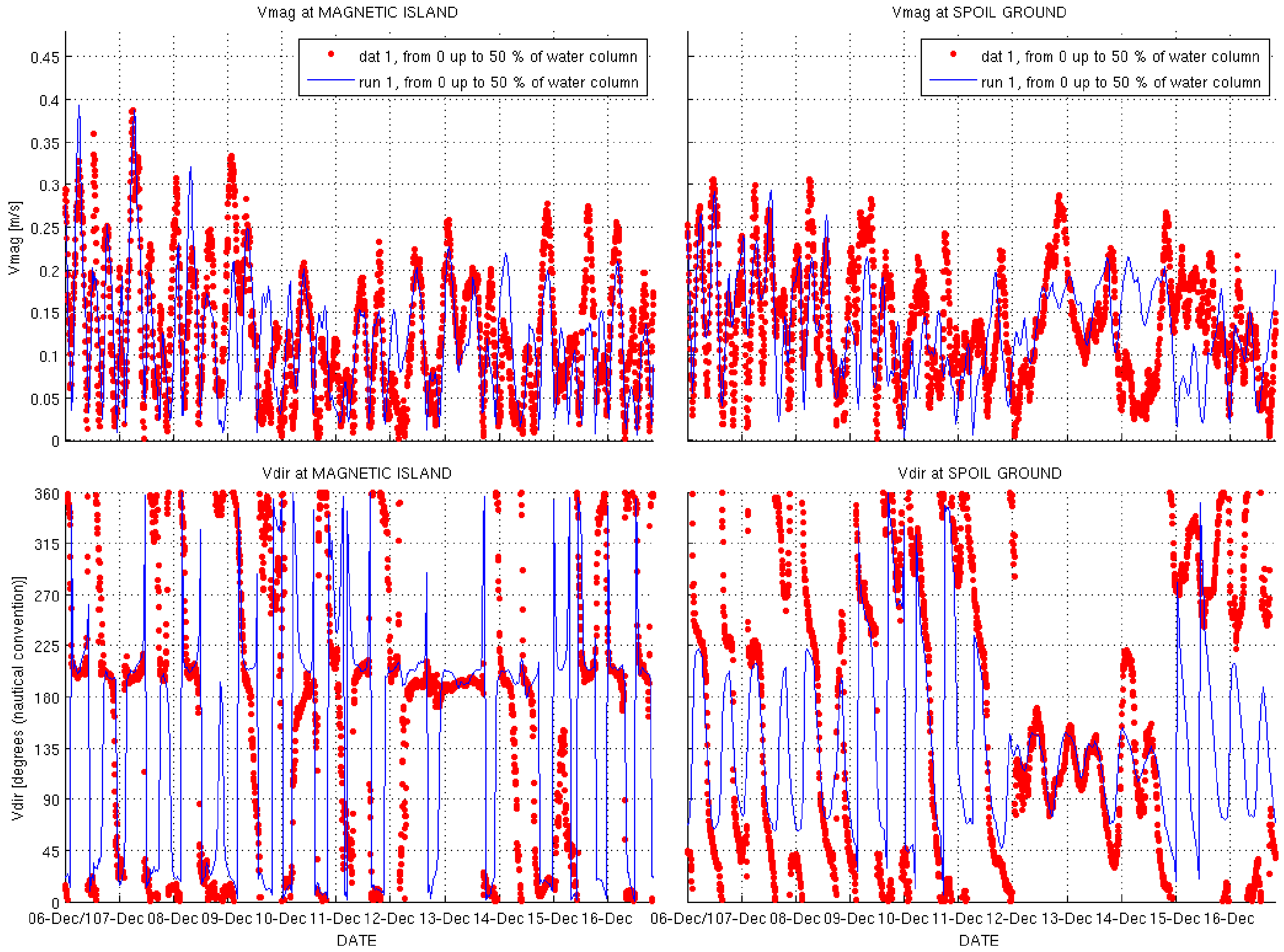


Figure 3-9 Velocity Validation Time Series – 2010 ADCP Data, Bottom 50%, 6-16 December – Magnetic Island (Left) and DMPA (Right)

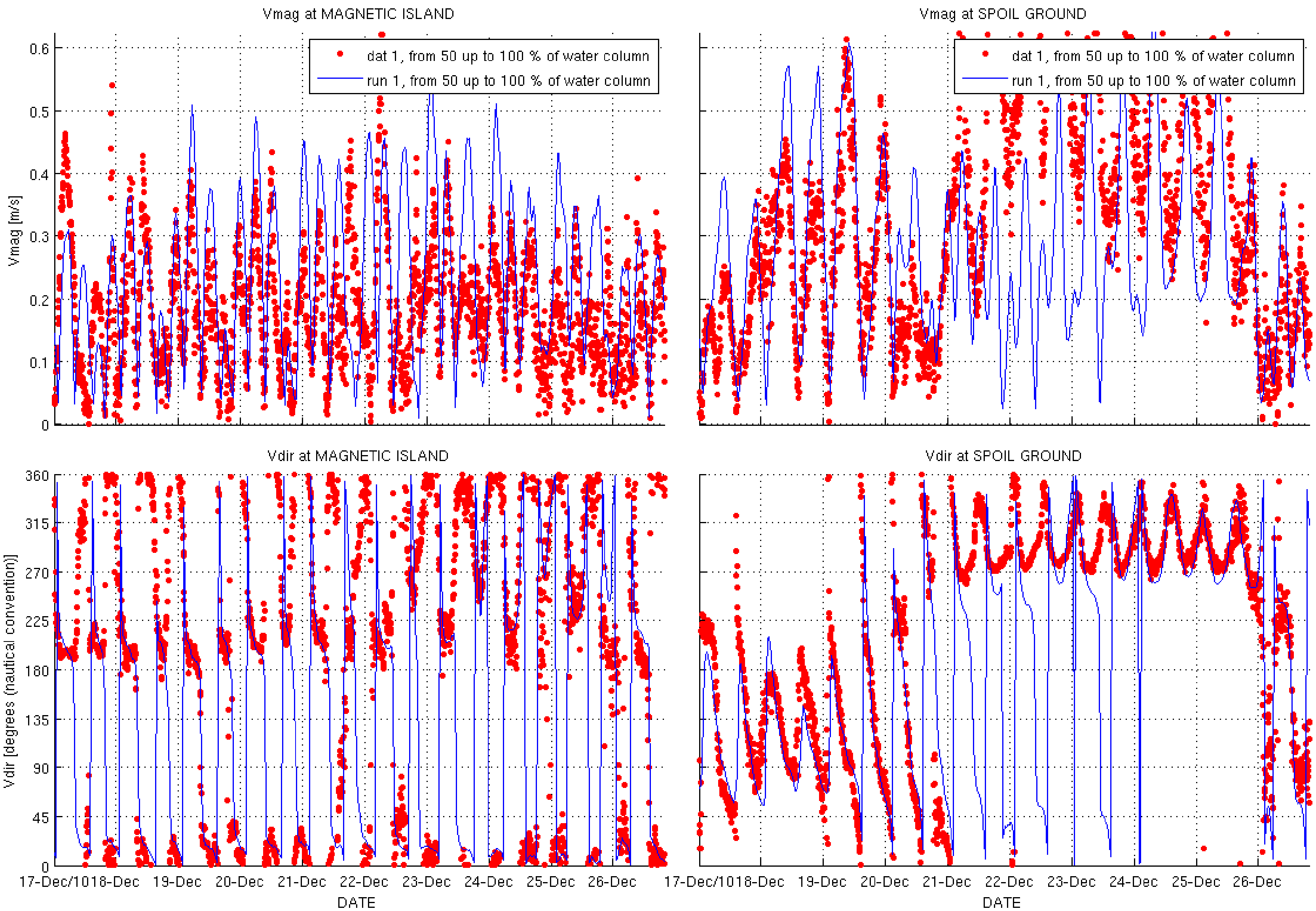


Figure 3-10 Velocity Validation Time Series – 2010 ADCP Data, Top 50%, 17-28 December – Magnetic Island (Left) and DMPA (Right)

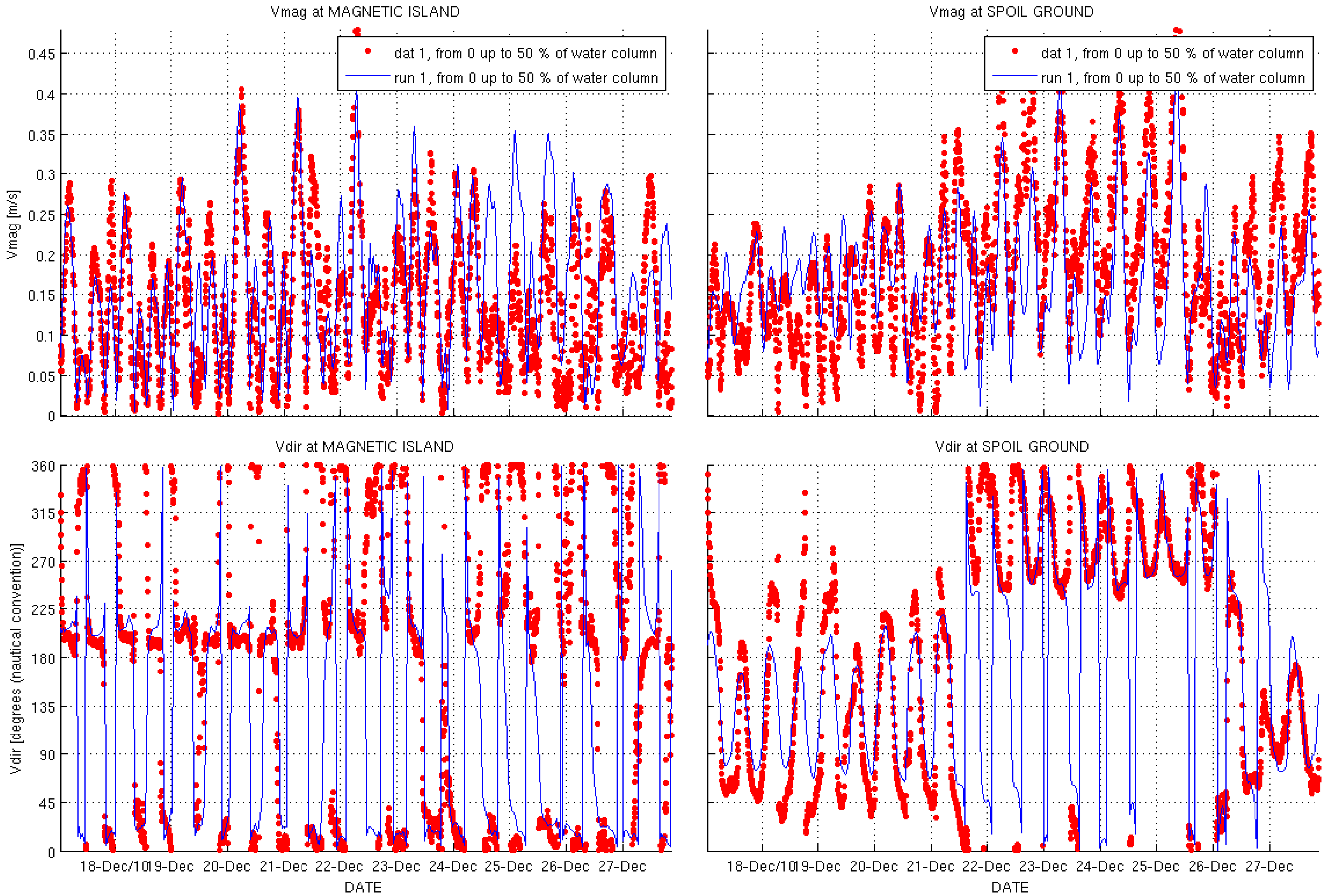


Figure 3-11 Velocity Validation Time Series – 2010 ADCP Data, Bottom 50%, 17-28 December – Magnetic Island (Left) and DMPA (Right)

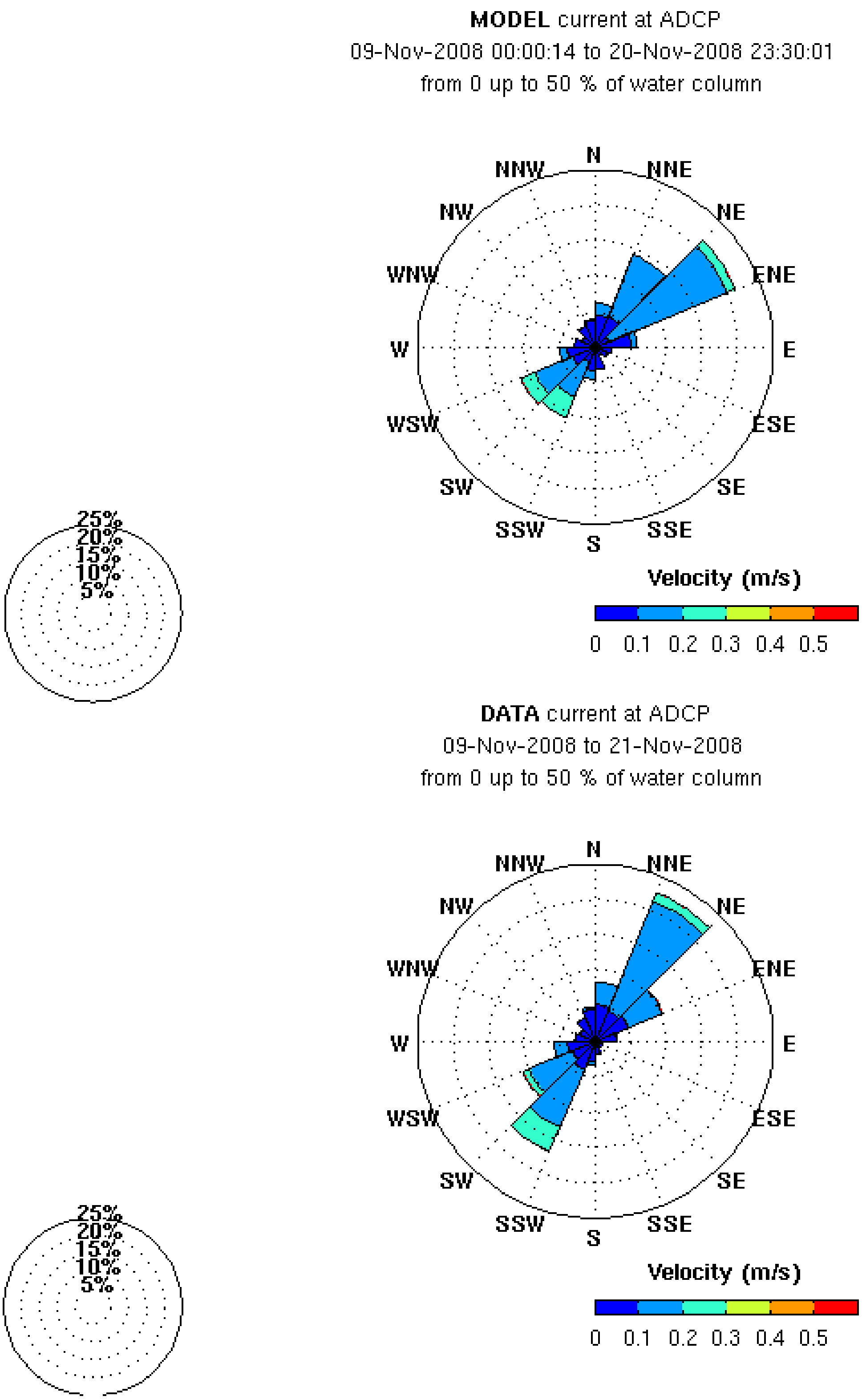


Figure 3-12 Velocity Validation Rose Plot – 2008 Platypus Channel ADCP Data – Bottom 50% Top – Model, Bottom – Data

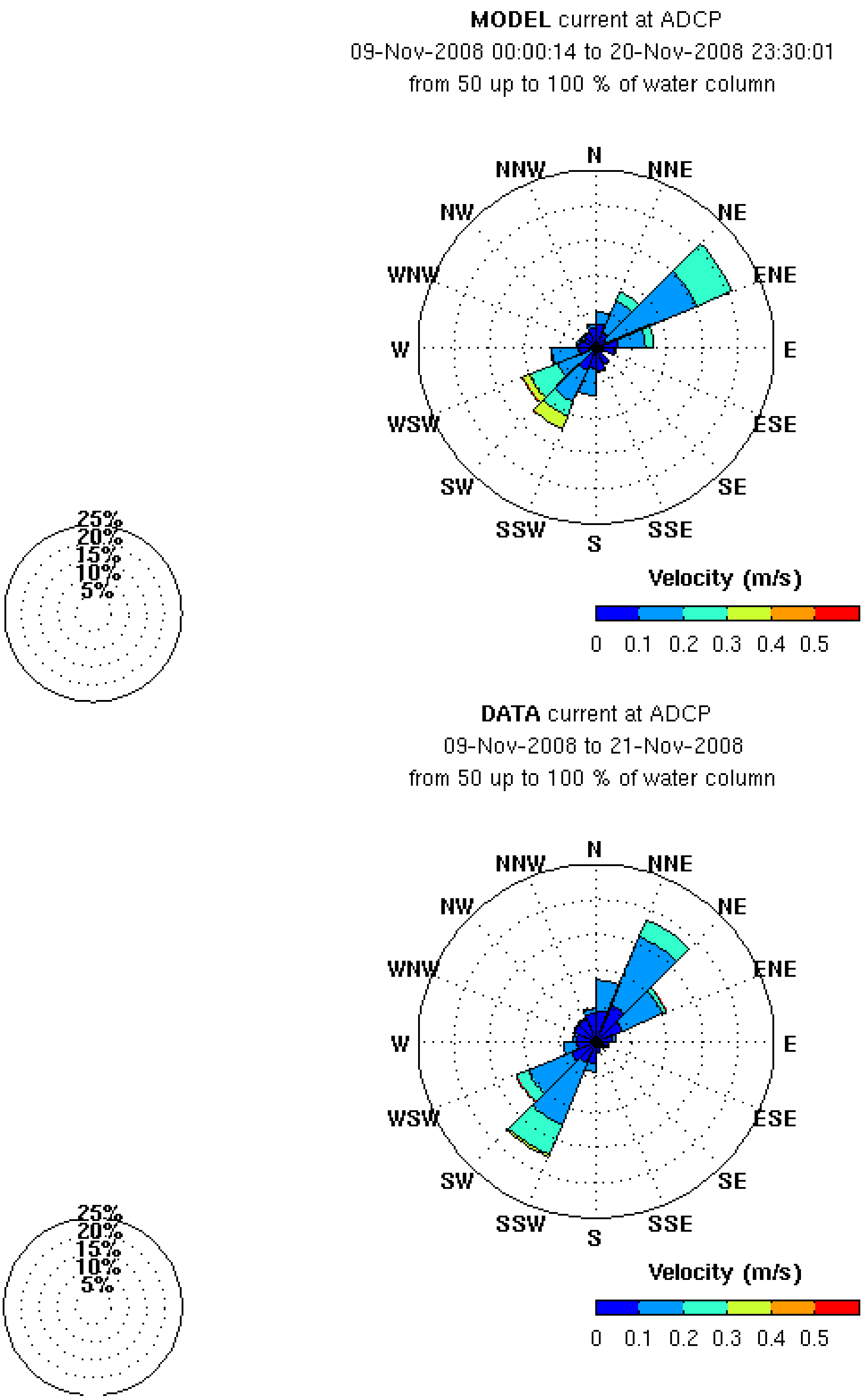


Figure 3-13 Velocity Validation Rose Plot – 2008 Platypus Channel ADCP Data – Top 50% Top – Model, Bottom – Data

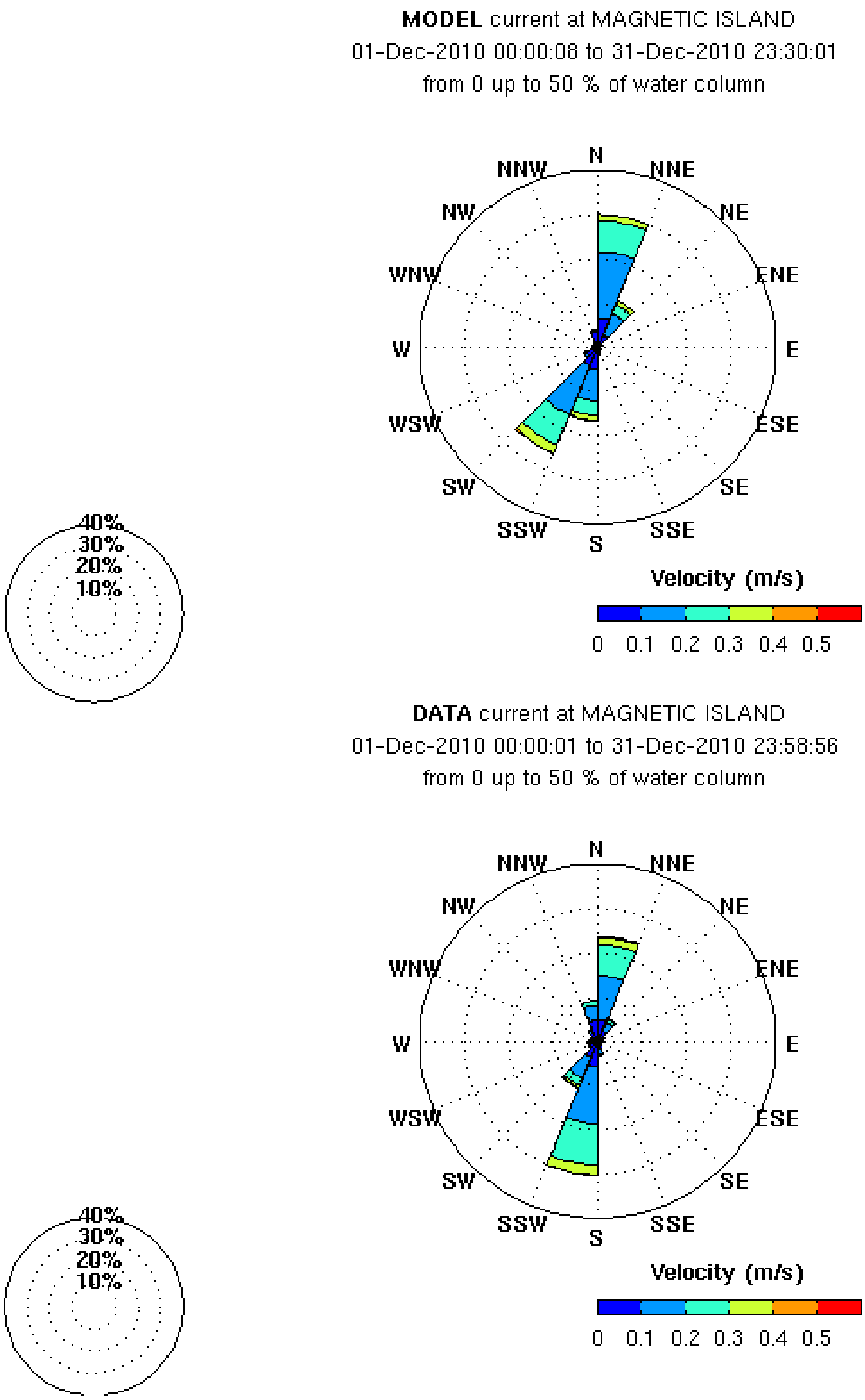


Figure 3-14 Velocity Validation Rose Plot – 2010 Magnetic Island ADCP Data – Bottom 50% Top – Model, Bottom – Data

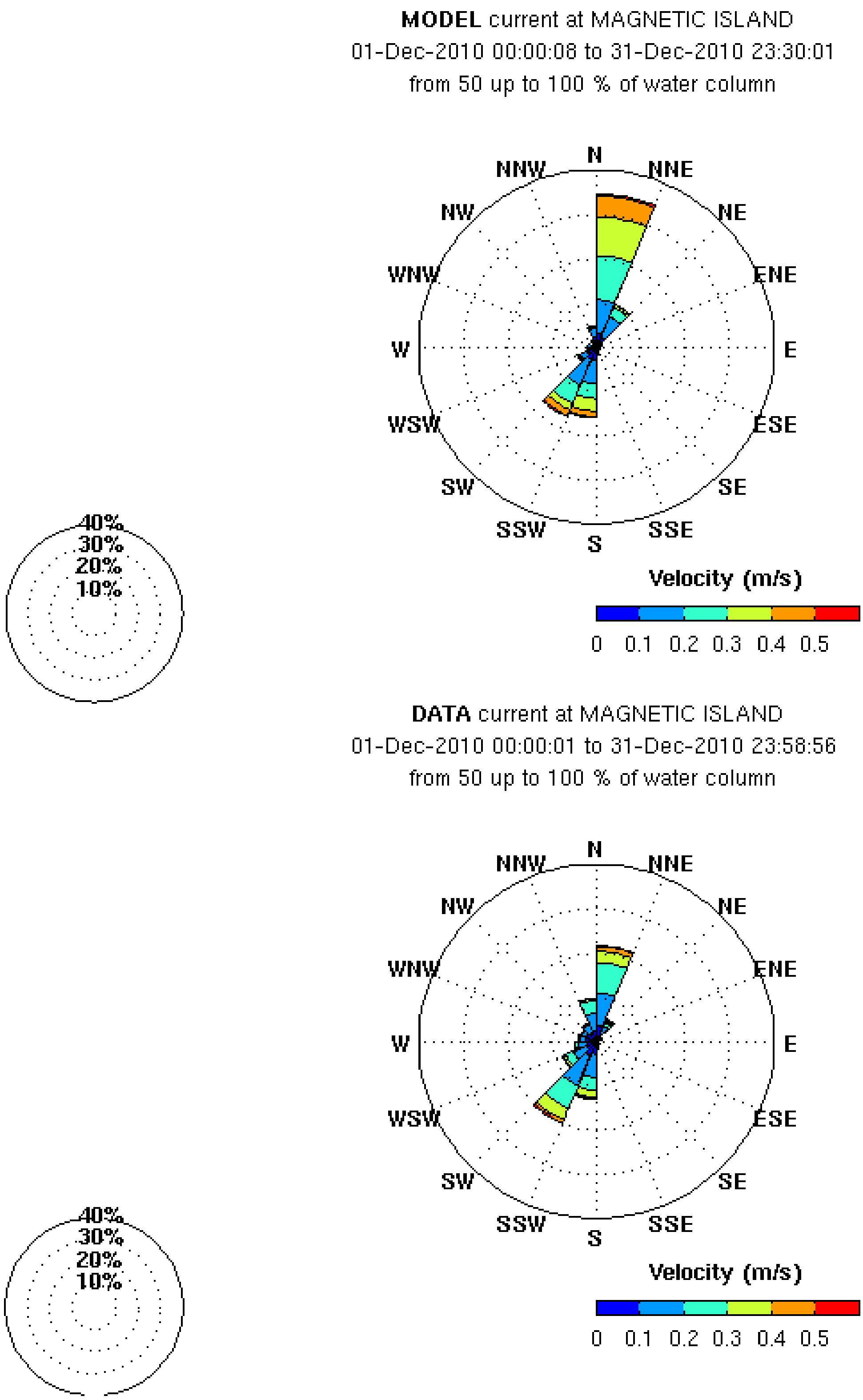
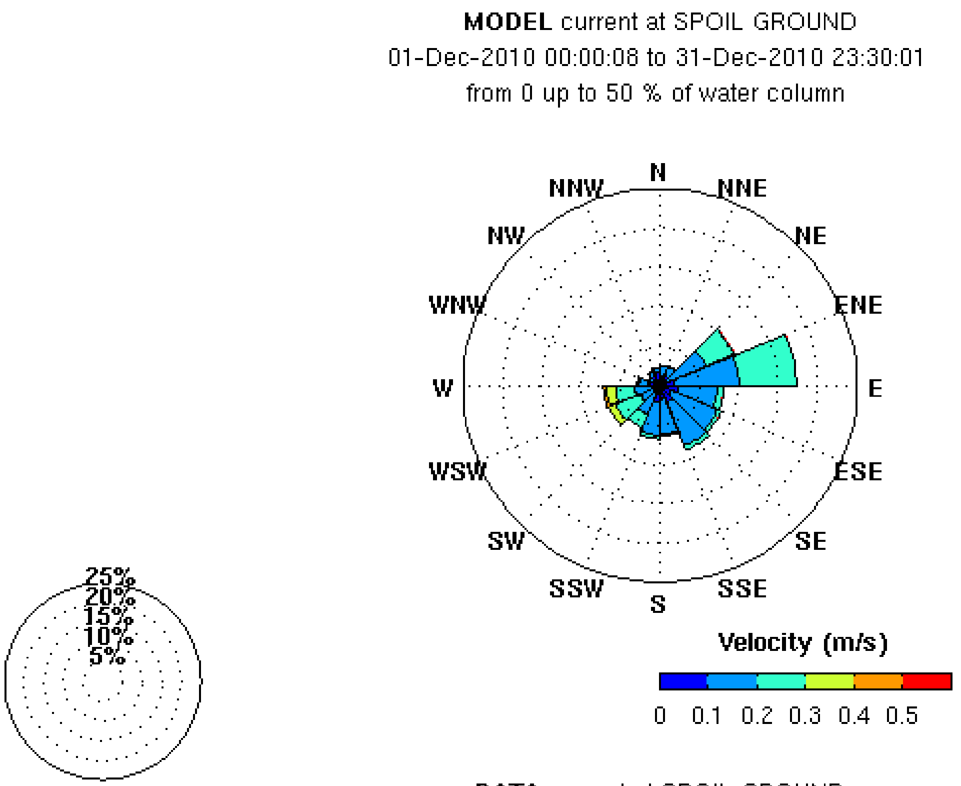


Figure 3-15 Velocity Validation Rose Plot – 2010 Magnetic Island ADCP Data – Top 50% Top – Model, Bottom – Data



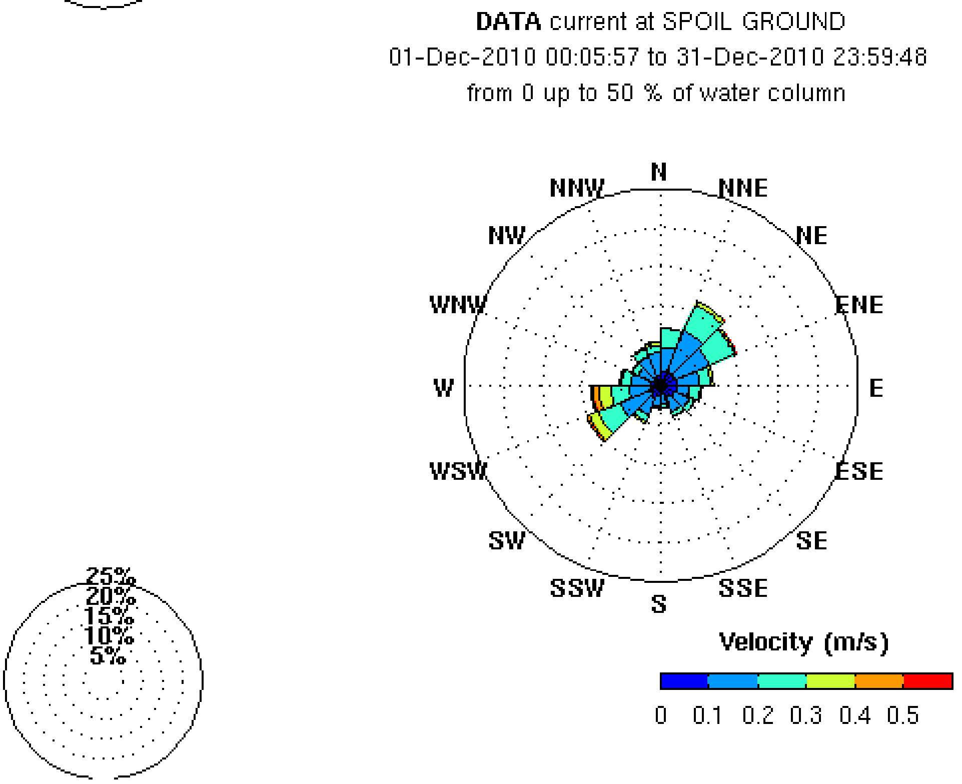


Figure 3-16 Velocity Validation Rose Plot – 2010 DMPA ADCP Data – Bottom 50% Top – Model, Bottom – Data

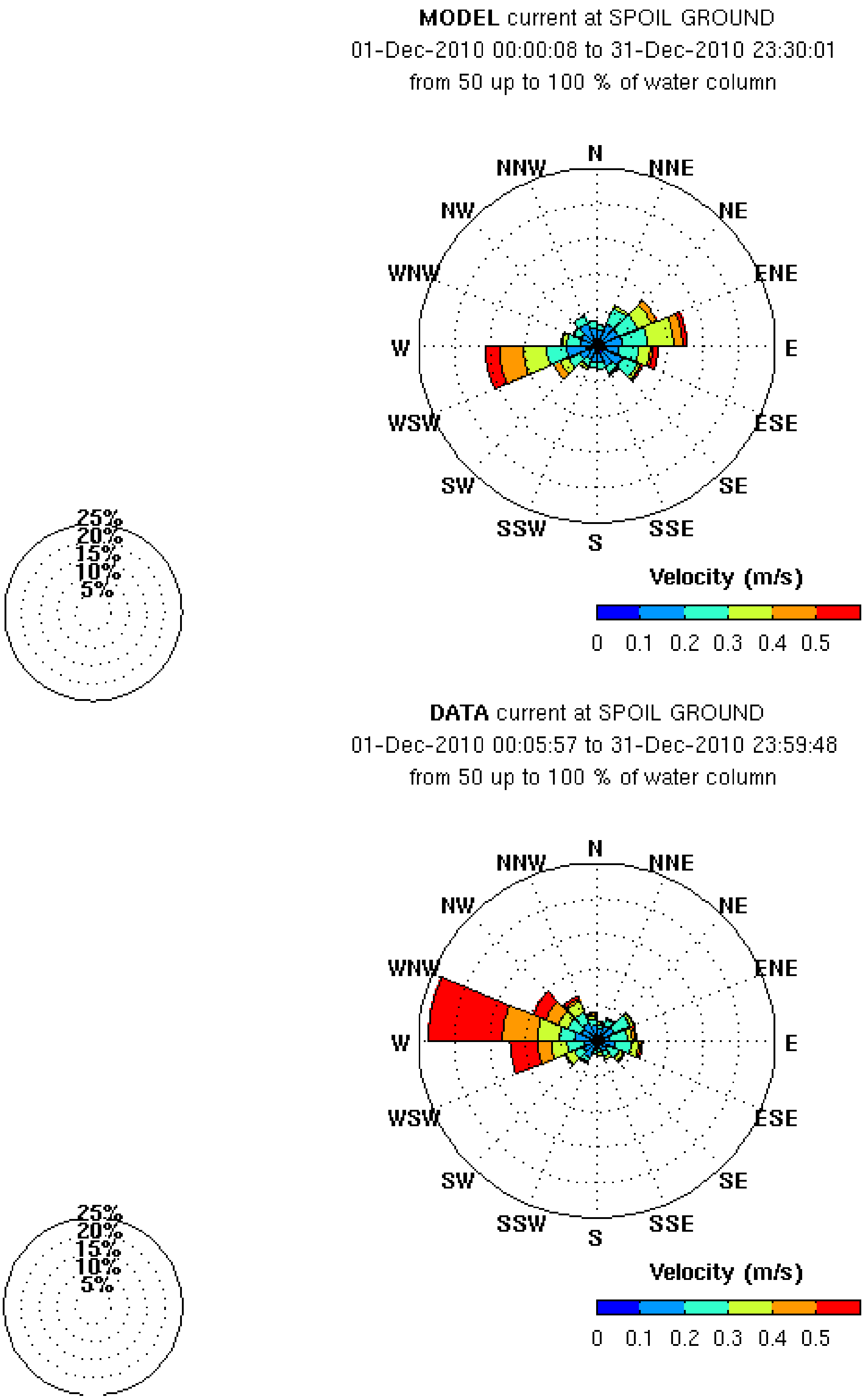


Figure 3-17 Velocity Validation Rose Plot – 2010 DMPA ADCP Data – Top 50% Top – Model, Bottom – Data

3.2 SWAN Wave Model Calibration Results

Measured wave data from the two ADCPs deployed in 2010 and from the DSITI Waverider Buoy were used to calibrate and validate the SWAN wave models (for deployment locations see Figure 3-2).

The results of the nested wave model calibration are shown in Figure 3-18, Figure 3-19 and Figure 3-20. Agreement between the measured and modelled wave heights, directions and peak periods is generally good, particularly with the DSITI wave buoy and the Magnetic Island ADCP. Some under-prediction bias is evident relative to the DMPA ADCP significant wave height measurements; however it is unclear why this would be significantly different from the DSITI wave buoy which was located within a relatively short distance of the DMPA. Some under-prediction bias is probably attributable to the non-stationary assumptions made in the wave model predictions.

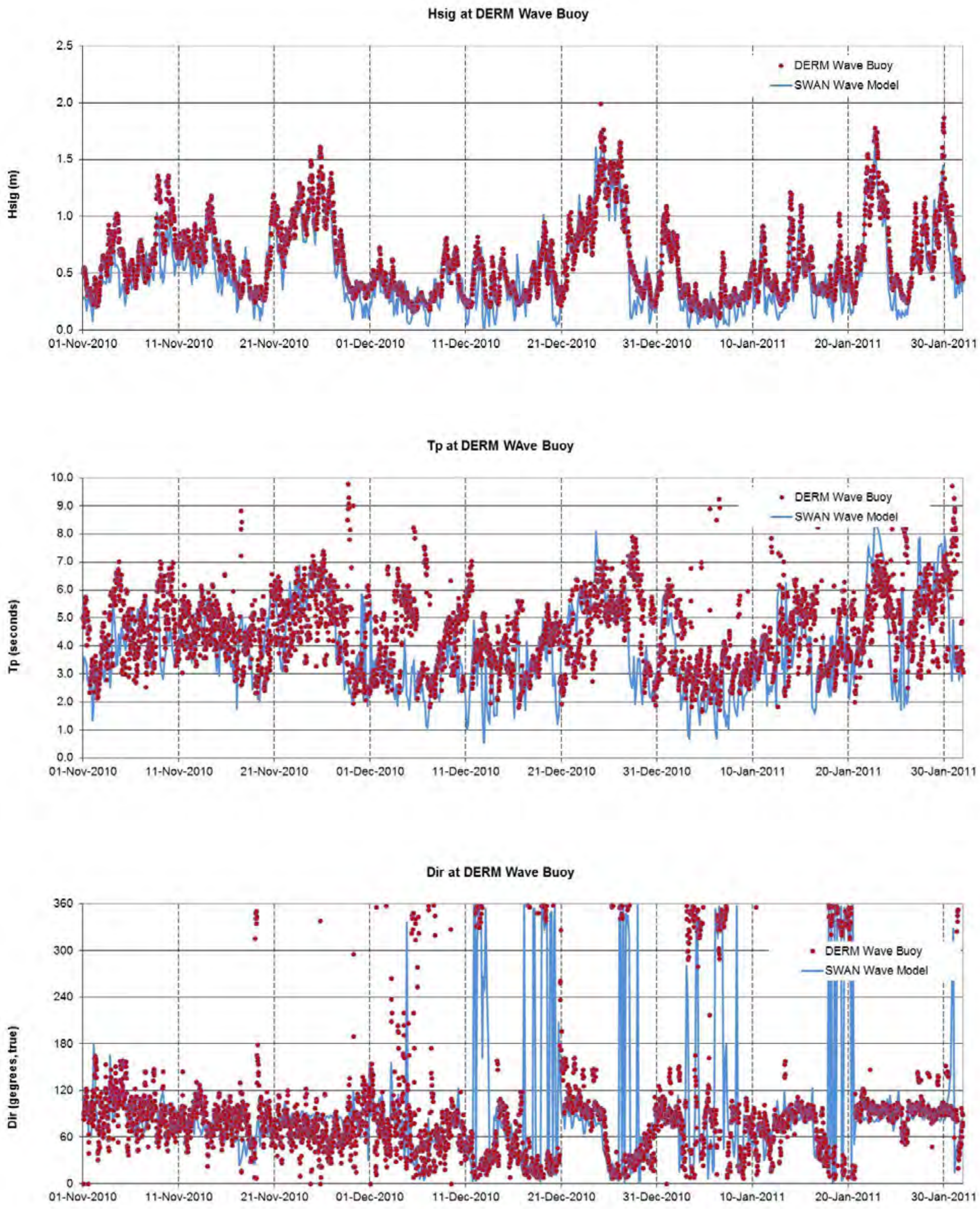


Figure 3-18 Wave Model Calibration – DSITI Waverider Buoy

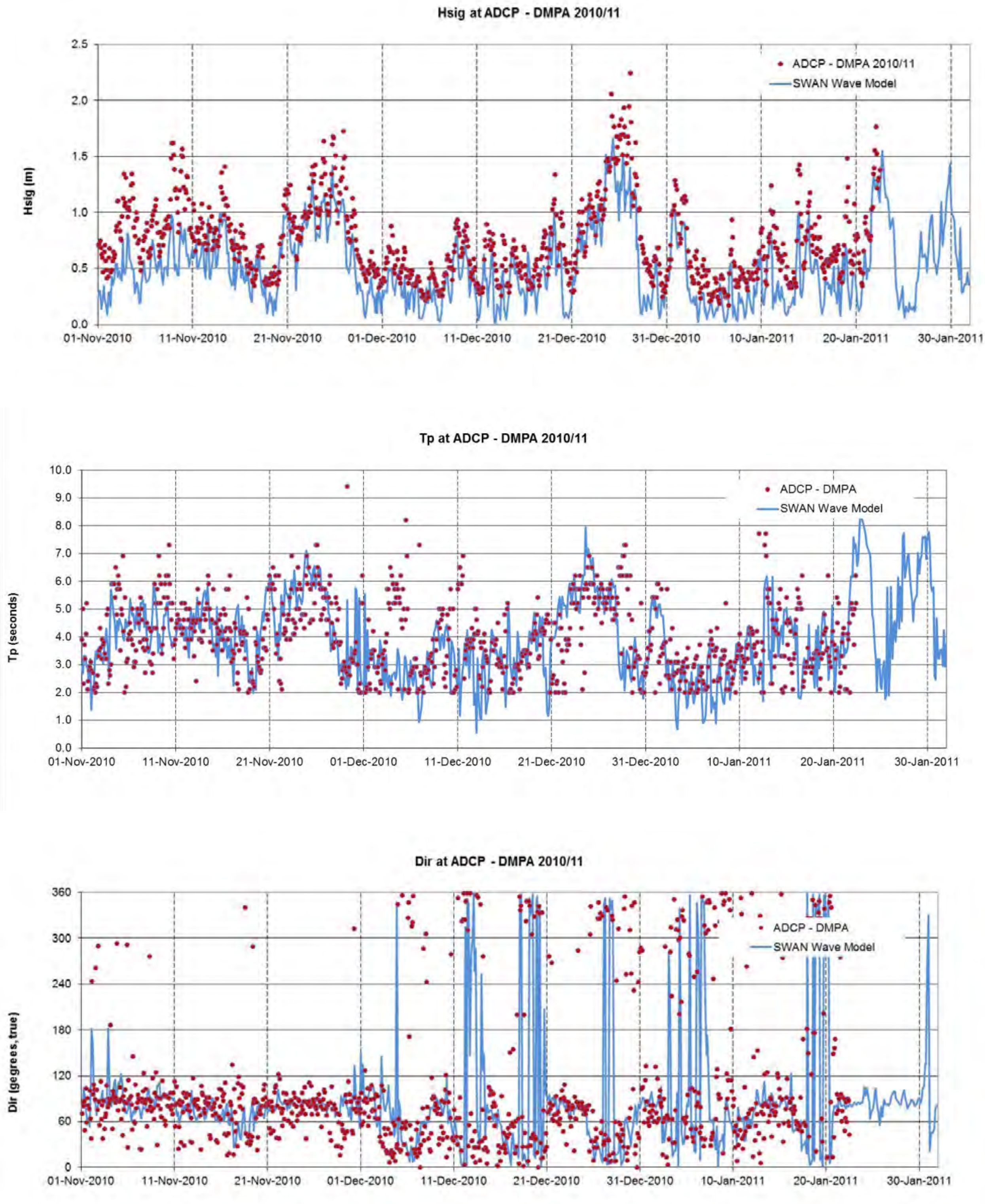


Figure 3-19 Wave Model Calibration – DMPA ADCP

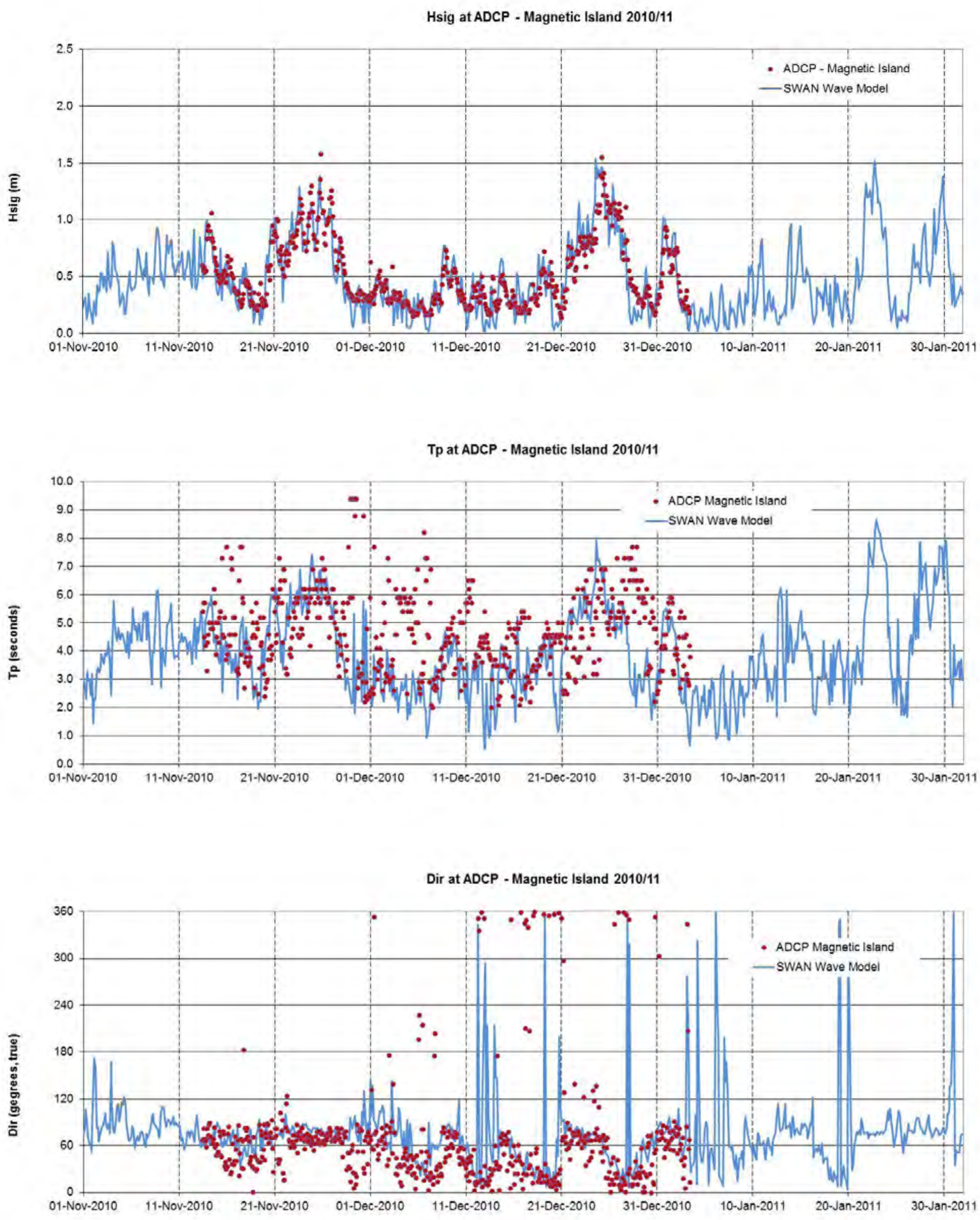


Figure 3-20 Wave Model Calibration – Magnetic Island ADCP

3.3 Advection-Dispersion Plume Modelling Validation

3.3.1 Data Collection

Dredge plume monitoring was conducted by BMT WBM in the nearshore and offshore areas of the Port of Townsville from 2nd - 5th January 2011. These measurements were used to assist in the validation of the advection-dispersion model and to guide the adoption of specific sediment loading rates for the proposed dredging activities.

The BMT WBM vessel "Resolution II" was used to undertake the field work. Weather conditions were relatively mild throughout the monitoring campaign. The vessel was equipped with an Acoustic Doppler Current Profiler (ADCP) which was configured in backscatter echo intensity mode to show in real time a surrogate of the suspended particle concentrations within the water column below the vessel. The ADCP was configured with real time navigation data from a differential GPS system as well as the ADCP's own inertial navigation system so that recorded backscatter intensities were time tagged and spatially located in real earth coordinates. Simultaneous measurements (water column profiles, water sample collection and backscatter echo intensities) were conducted on a series of transects through the dredge plume at each monitoring location.

3.3.2 Data Processing

Measurements of turbidity in Nephelometric Turbidity Units (NTU) and Total Suspended Solids (TSS) results from the laboratory were compared in order to establish the TSS – NTU relationship shown in Figure 3-21. The turbidity measurements (converted into TSS) and the water sample TSS results were then used as the basis for converting the ADCP backscatter measurements to TSS concentrations. Plume water samples were also analysed for suspended sediment Particle Size Distribution (PSD), with the results shown in Figure 3-22.

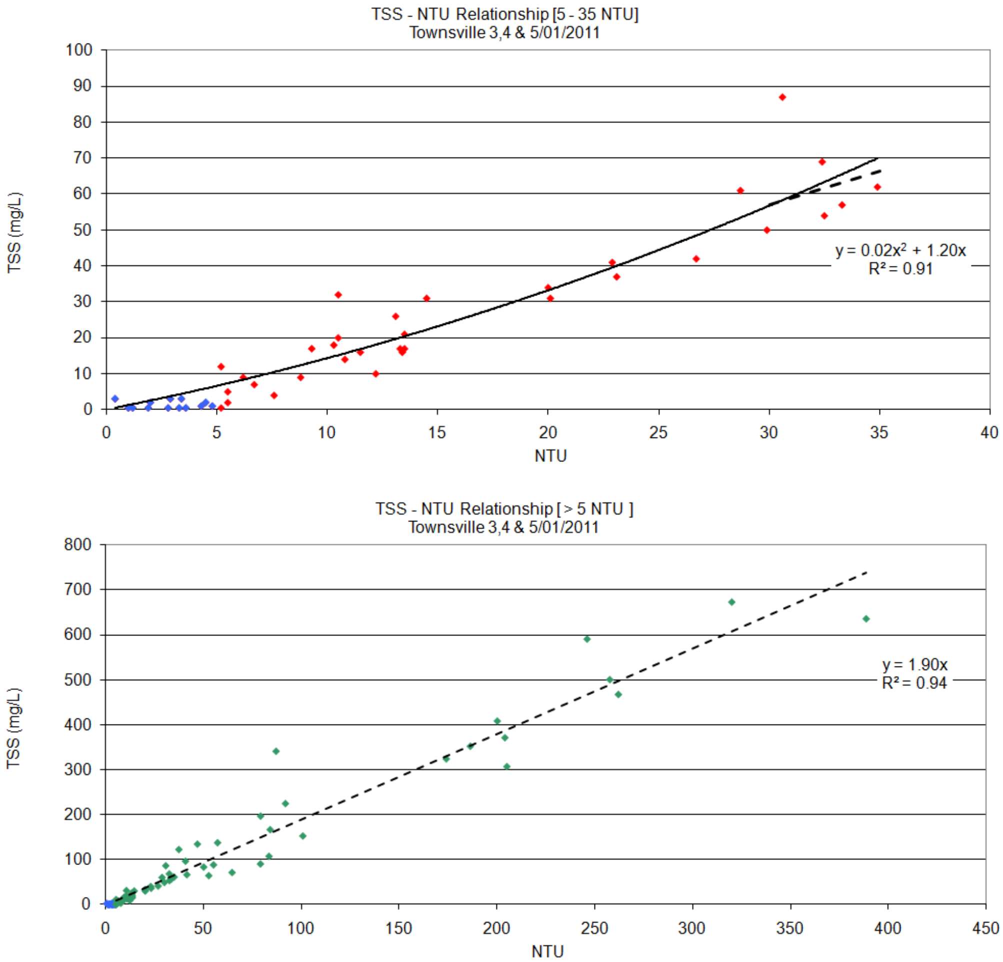


Figure 3-21 TSS – NTU Relationship for Maintenance Dredging Plume Material

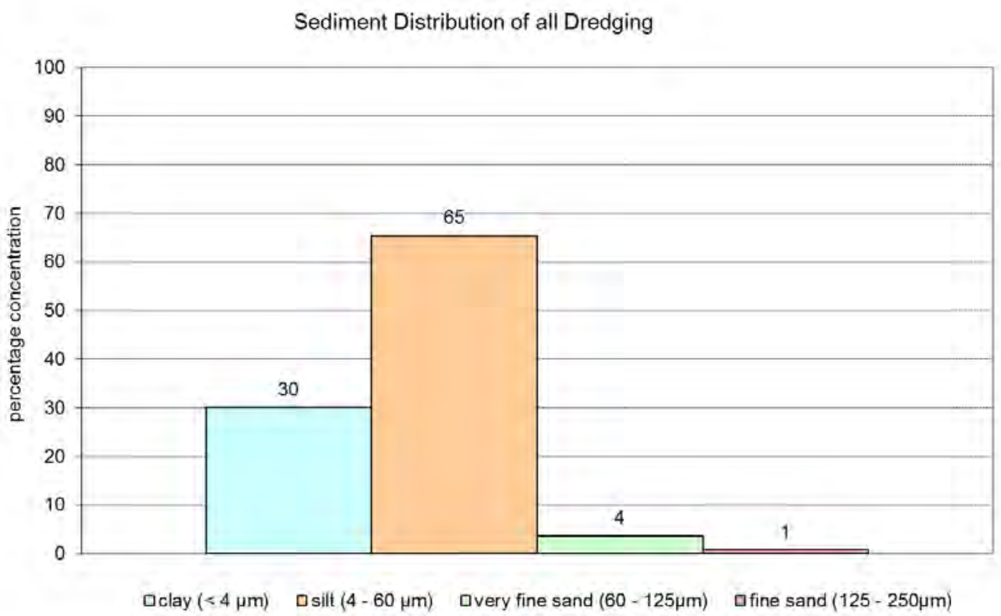


Figure 3-22 Dredge Plume Particle Size Distribution

3.3.3 Model Parameters

Dredging works cause the generation of plumes of suspended sediment through a number of potential sources/mechanisms. The major sources considered for the modelling of the Trailing Suction Hopper Dredge (TSHD) Brisbane were:

- Sediment entrainment at the draghead during dredging;
- Overflow of sediment from the hopper; and
- Placement of material at the Dredge Material Placement Area (DMPA) by hopper release.

The measured 3D TSS concentrations from the January 2011 ADCP transects were compared to simulations of plume dispersion using the 3D TUFLOW FV coupled advection-dispersion and hydrodynamic model in order to calibrate the model parameters.

The dredging logs were obtained and used to locate the dredge and also to determine the mode of operation (i.e. dredging, dredging with overflow or placement).

Prediction of dredge plume impacts involves a number of components, namely:

- Source rate definition, i.e., mass load and characteristics of sediment entrained by the dredging activities;
- Prediction of plume advection/dispersion; and
- Prediction of plume settling.

The first of these is the most variable, and depends intimately on the type of dredging activities (e.g., type and size of dredge) as well as the material being excavated. As such, this component of the dredge plume modelling is also the most subject to variation. Initially, the source parameters were chosen based on engineering judgement, experience on similar projects and literature values. These parameters were then modified during the calibration process on the basis of comparisons with the measured data. The source terms adopted after model calibration are summarised below:

TSHD “BRISBANE”

- Total source while overflow dredging in the channel: 250kg/s.
- Total source while overflow dredging in the outer harbour: 50kg/s.
- Source during placement: 200kg/s.

A higher rate of sediment release was adopted during channel dredging than during outer harbour dredging in order to more closely match the measured plume concentrations. The dredge travelled at a higher speed during channel dredging and did not have the manoeuvring constraints found in the outer harbour, and therefore tended to release more sediment.

The material released during the maintenance dredging activity was assumed to be composed of 30% clay, 65% silt and 5% fine sand (based on the particle size distribution of sampled sediment - Figure 3-22), with assumed settling velocities of 1 x 10^{-4} m/s, 5 x 10^{-4} m/s and 1 x 10^{-2} m/s respectively.

The dredge plume boundary condition was applied as a depth-averaged source into the model as there was no consistent indication in the near-field ADCP data that the source was particularly concentrated in any one part of the water column during either dredging or placement.

The General Ocean Turbulence Model (http://www.gotm.net/) was used to control vertical mixing of both momentum and sediment. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

Examples of the results of the plume model validation exercise are illustrated in Figure 3-23 and Figure 3-24. The full collection of plume model validation plots are presented in Attachment C of this appendix. The upper panels in each figure show transects through the dredge plume, with contour plots of TSS measured by the ADCP (on the left) and modelled (on the right). The lower panels show a plan view of depth-averaged TSS, with the model results in the background and the ADCP-measured TSS shown as a black-bordered line along the transect. A red cross marks the start point of the transect (0m chainage in the upper panel).

The plume model validation results generally indicate that the model is accurately reproducing the pattern of suspended sediment distribution associated with dredge plumes. The magnitude of the suspended sediment concentration is overestimated in some cases, especially during dredging in the outer harbour. The accuracy of the ADCP data in the near field is sometimes uncertain due to bubbles and turbulence generated by the dredge propwash. Given the complexity of the modelling task, and the highly three-dimensional nature of plumes and temporal variation in dredge discharge, the model performance is considered to be good.

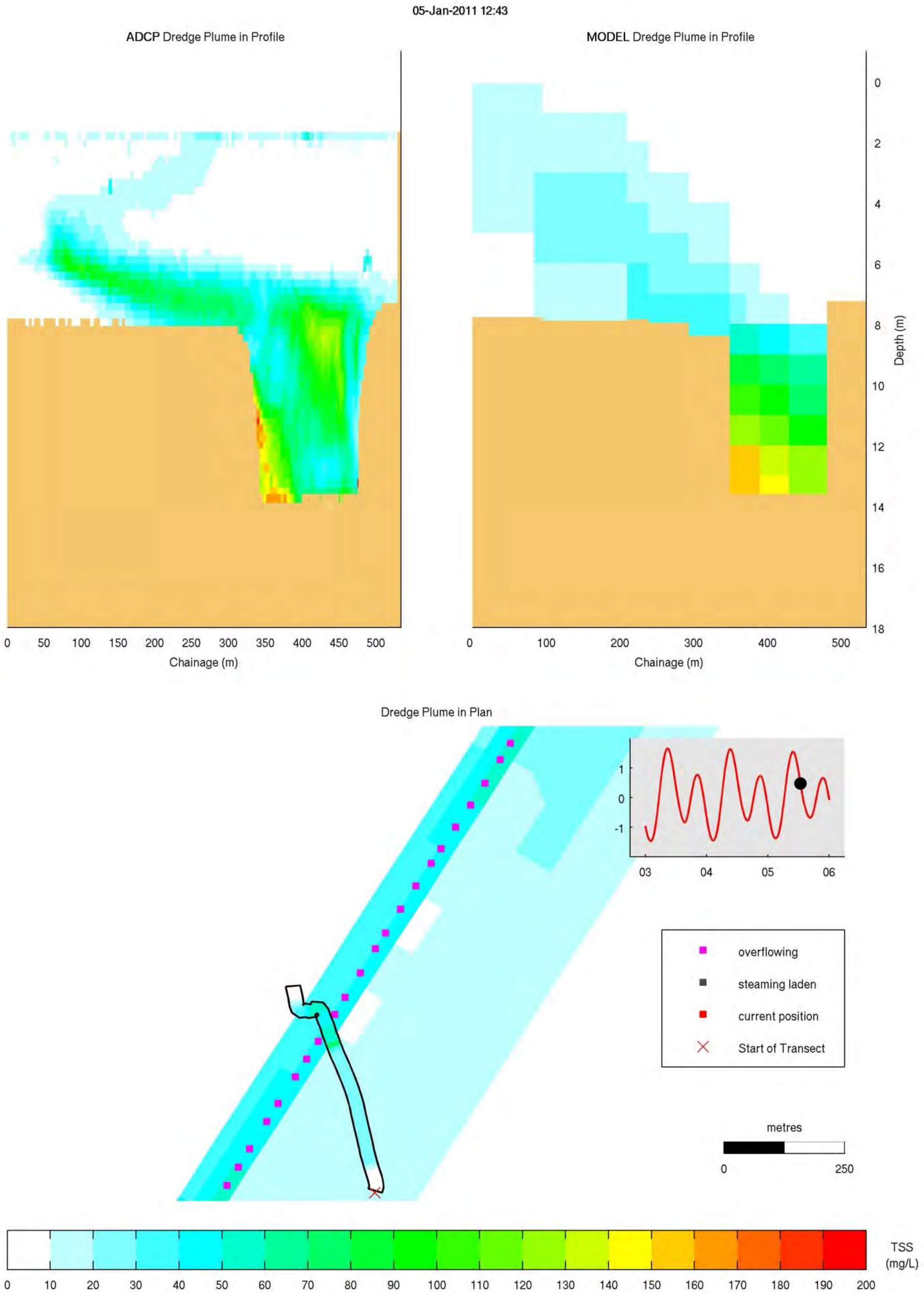


Figure 3-23 Dredge Plume Model Validation – Platypus Channel – 5/1/2011 ADCP Data

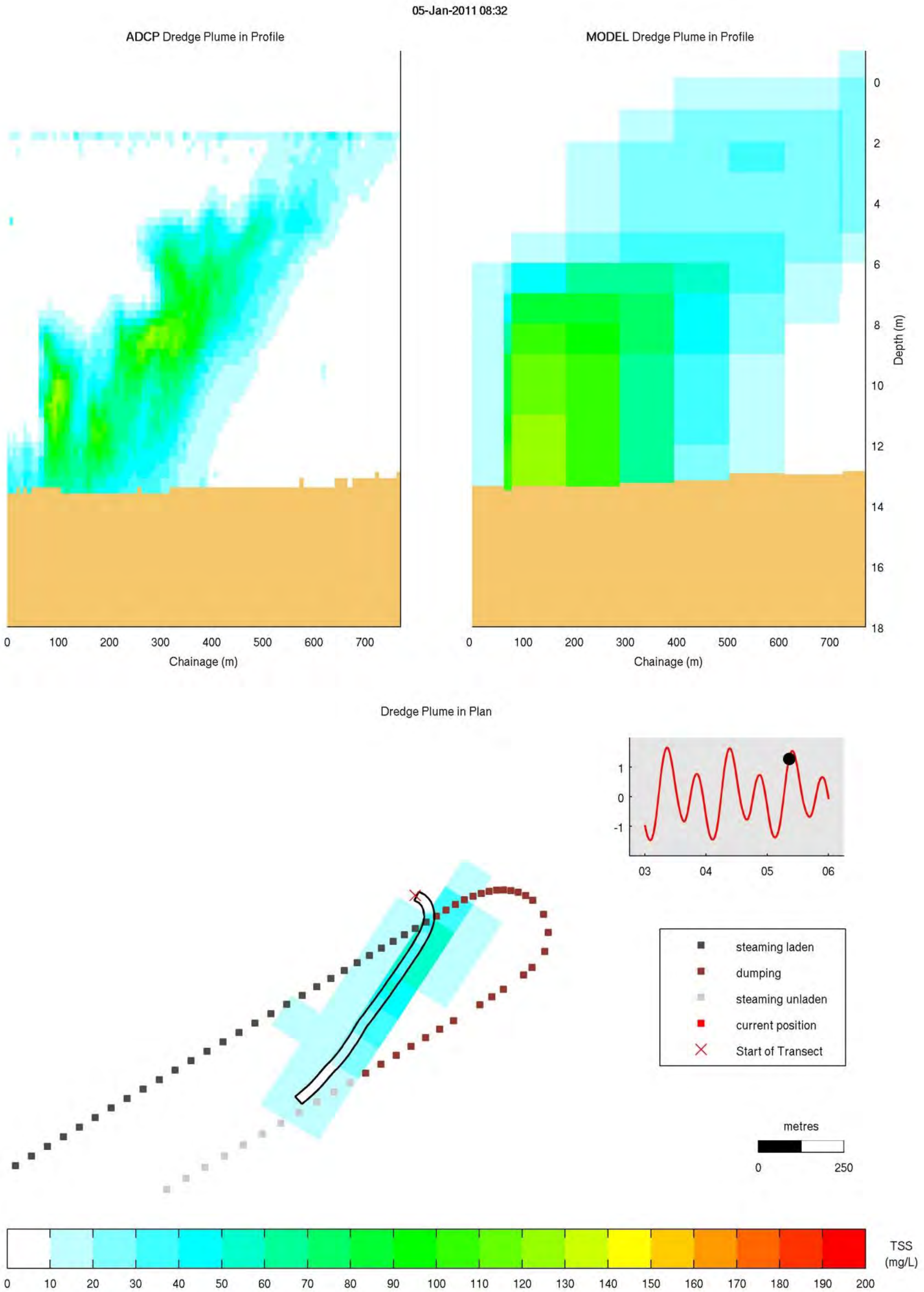


Figure 3-24 Dredge Plume Model Validation – DMPA – 5/1/2011 ADCP Data

3.4 Resuspension Model Calibration

In order to use the TUFLOW FV model to estimate the natural sediment resuspension dynamics in the study area, the model was calibrated using available measurements of ambient turbidity.

The cohesive sediment module of TUFLOW FV simulates the exchange of sediments between the bed and the water column. The effective clear water sediment settling velocity of each sediment fraction, w_s, is directly specified and is assumed to have no dependence on either suspended sediment concentration (e.g. flocculation or hindered settling). The modelled rate of sediment deposition (in g/m^2/s) is a function of the near-bed sediment concentration (TSS), the still-water fall velocity (w_s) and the bed shear stress (τ_b), according to the relationship:

$$Q_d = w_s.TSS.\max\left(0, 1 - \frac{\tau_b}{\tau_{cd}}\right)$$ units [g/m^2/s]

where τ_{cd} is a model parameter defining the critical shear stress for deposition. As such, sediment settling is reduced below its still water value by the action of bed shear stress and associated vertical mixing in the water column. The rate of erosion is calculated according to:

$$Q_e = E.\max\left(0, \frac{\tau_b}{\tau_{ce}} - 1\right)$$ units [g/m^2/s]

where Q_e is the erosion rate, E is the erosion rate constant and τ_{ce} is the critical bed shear stress for erosion.

The General Ocean Turbulence Model was used to control vertical mixing of both momentum and sediment. A Smagorinsky model was used for the estimation of the horizontal eddy viscosity and diffusivity coefficients.

The calibration process led to the adoption of the following model parameters:

- Critical shear stress for erosion τ_{ce} = 0.2 Pa;
- Critical shear stress for deposition τ_{cd} = 0.1 Pa; and
- Erosion rate constant E = 0.005 g/m^2/s.

The initial model bed was composed of 25% clay, 50% silt and 25% fine sand, with assumed settling velocities of 1 x 10^{-4} m/s, 5 x 10^{-4} m/s and 1 x 10^{-2} m/s respectively. The model was run for an initial "warm up" period to allow the sediment types to redistribute within the model. This process allowed the bed composition in each area to evolve towards an initial condition which was likely to reflect the actual local natural bed composition.

YSI 6600 water quality instruments were deployed in Cleveland Bay in March and July 2012 to collect 12 months of baseline water quality data. These baseline data were used to develop trigger levels for use in proposed capital dredging projects, and were also used to review existing programs and dredging practices as part of POTL's commitment to continual improvement.

The YSI water quality instruments were deployed at two locations close to the mainland (the Strand and Virago Shoal) and three locations near the east coast of Magnetic Island (Geoffrey Bay, Florence Bay and Picnic Bay) (Figure 3-25).

Figure 3-25 Locations Used for Model Calibration

These instruments logged data for a range of parameters, including turbidity, dissolved oxygen (DO), pH and conductivity, once every 10 minutes. The instruments also recorded photosynthetically active radiation (PAR) data, which is an indicator of light available to sensitive receptors (e.g. seagrass and corals). Terrestrial PAR sensors on Magnetic Island and the mainland also allowed light attenuation through the water column (due to turbidity) to be calculated.

The instruments were mounted on secure frames placed on the sea bed, thereby measuring water quality at the location of benthic ecosystems (i.e. seagrass and coral). The instruments were deployed in the following approximate water depths:

- The Strand: -3 m LAT.
- Virago Shoal: -3 m LAT.
- Picnic Bay: -4 m LAT.
- Geoffrey Bay: -5 m LAT.
- Florence Bay: -7 m LAT.

Comparisons between measured and modelled turbidity are presented in Figure 3-26, Figure 3-27 and Figure 3-28. The ambient TSS time series is plotted as a blue line, while measured TSS is shown as red dots. The model did capture the overall suspended sediment dynamics reasonably well, including the overall magnitude of suspended sediment concentrations during several resuspension events. There was a significant discrepancy between measured and modelled turbidity during early March 2013 at The Strand and late February 2013 at Virago Shoal, however it is uncertain whether the data recorded during this period, especially at The Strand, is reliable (wave conditions during this period were not energetic). It is possible that freshwater inflows from Ross Creek and Ross River in late February / early March 2013 may have caused the increased turbidity at these nearshore locations and the model is not adequately representing these inflows (though they are included in the model). Note that the ambient turbidity predictions are inherently less accurate than the dredging-related turbidity simulations due to the greater uncertainty in the assumptions associated with modelling ambient sediment dynamics. The validation results indicate that the model is able to adequately reproduce natural variations in ambient turbidity in the study area.

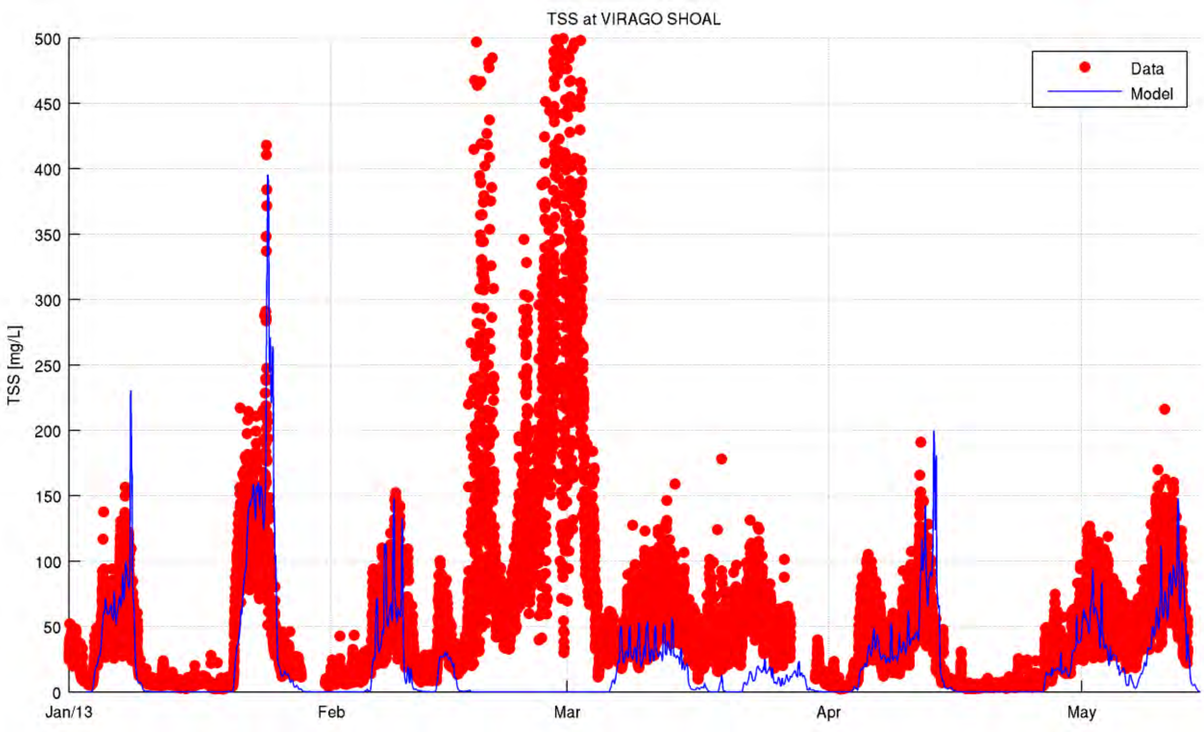
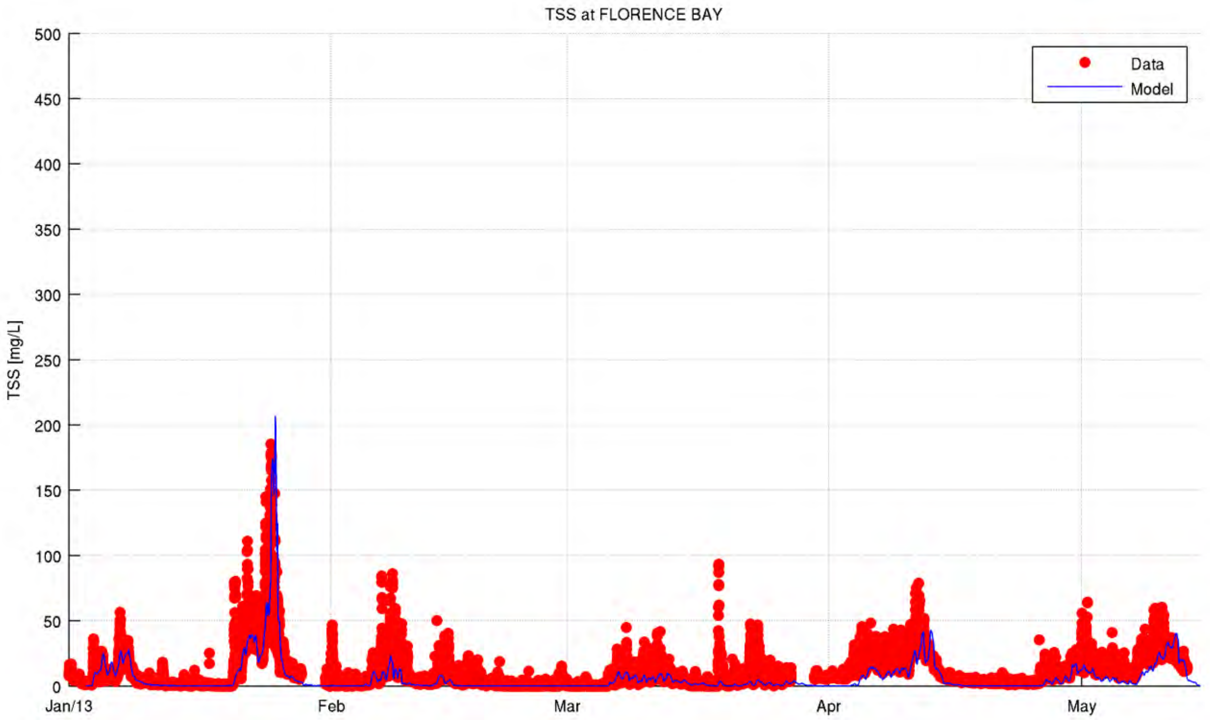


Figure 3-26 Measured and Modelled Suspended Sediment Concentrations at Virago Shoal



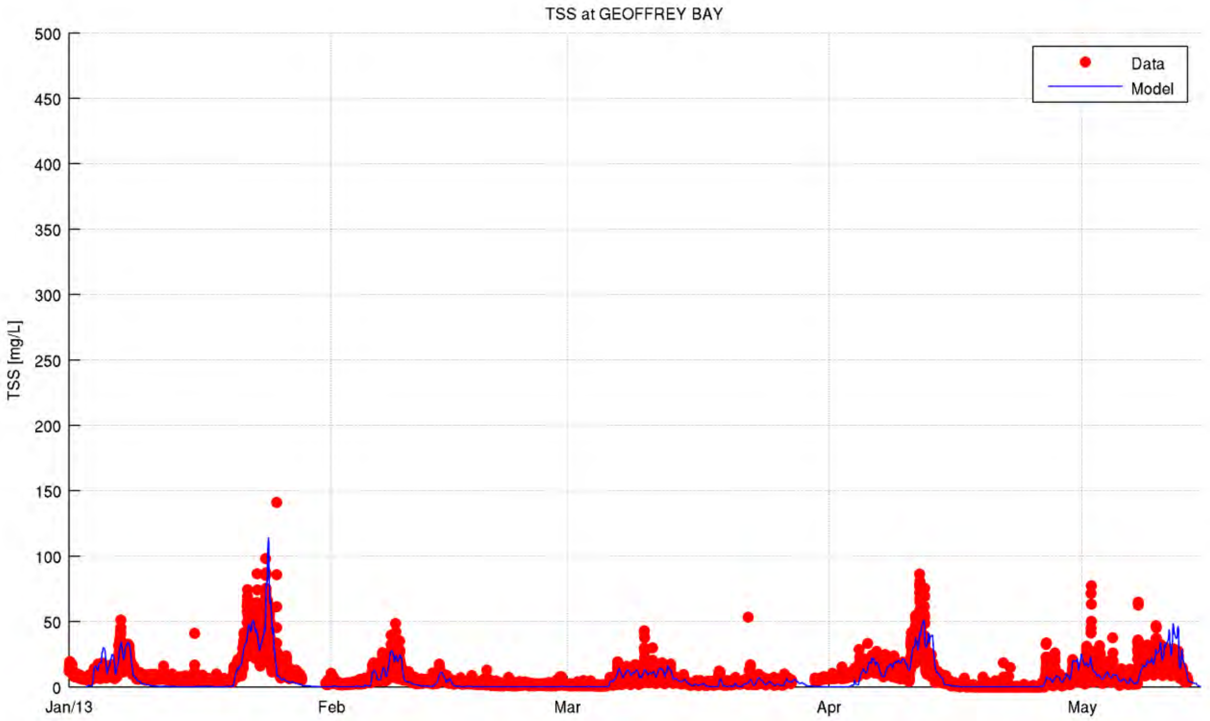


Figure 3-27 Measured and Modelled Suspended Sediment Concentrations at Florence Bay (Top) and Geoffrey Bay (Bottom)

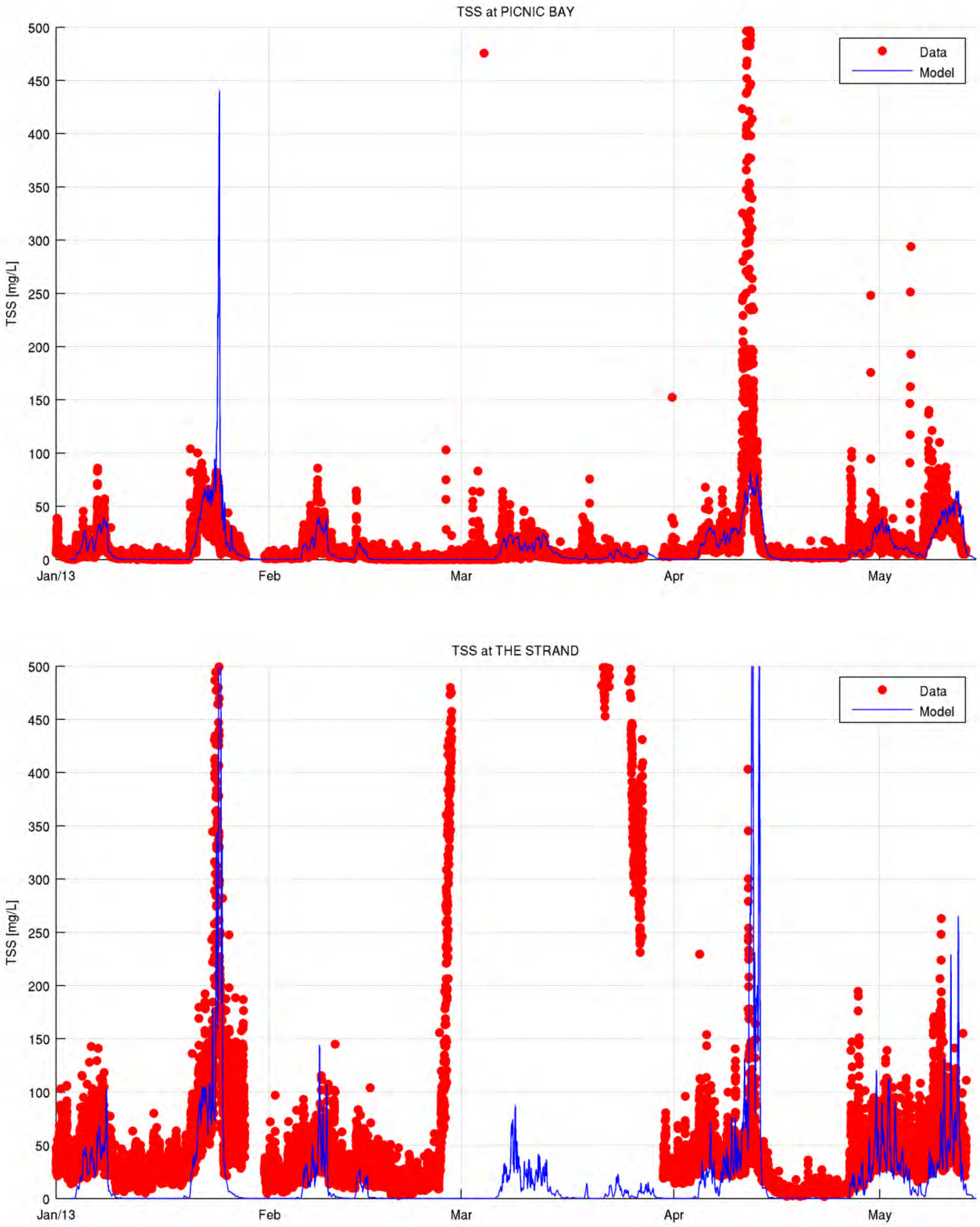


Figure 3-28 Measured and Modelled Suspended Sediment Concentrations at Picnic Bay (Top) and The Strand (Bottom)

4 Hydrodynamic Impact Assessments

Following setup, calibration and validation of both the hydrodynamic and advection dispersion models, a series of hydrodynamic scenarios were executed and interrogated. The general intent of these scenarios was to provide direct information on design conditions and potential hydrodynamic impacts. These scenarios are described below.

4.1 Existing Hydrodynamics

The validated hydrodynamic model was firstly used to illustrate the existing patterns of hydrodynamics within the study area.

For this purpose the model was run from 1/11/2010 to 1/12/2010, a period which included a period of the prevailing strong SE winds. The wind magnitude and direction for the period in the vicinity of the Port is shown in Figure 4-1. The wind rose measured at the Cleveland Bay gauge (for location refer Figure 2-5) and the wave rose measured at the DSITI Waverider buoy for this period are shown in Figure 4-2. The wave and wind roses for the same locations during the period 2008-2011 are shown in Figure 4-3. Comparison of these figures indicates that the modelled period is broadly representative of the average conditions, though with a slightly higher percentage of SE winds.

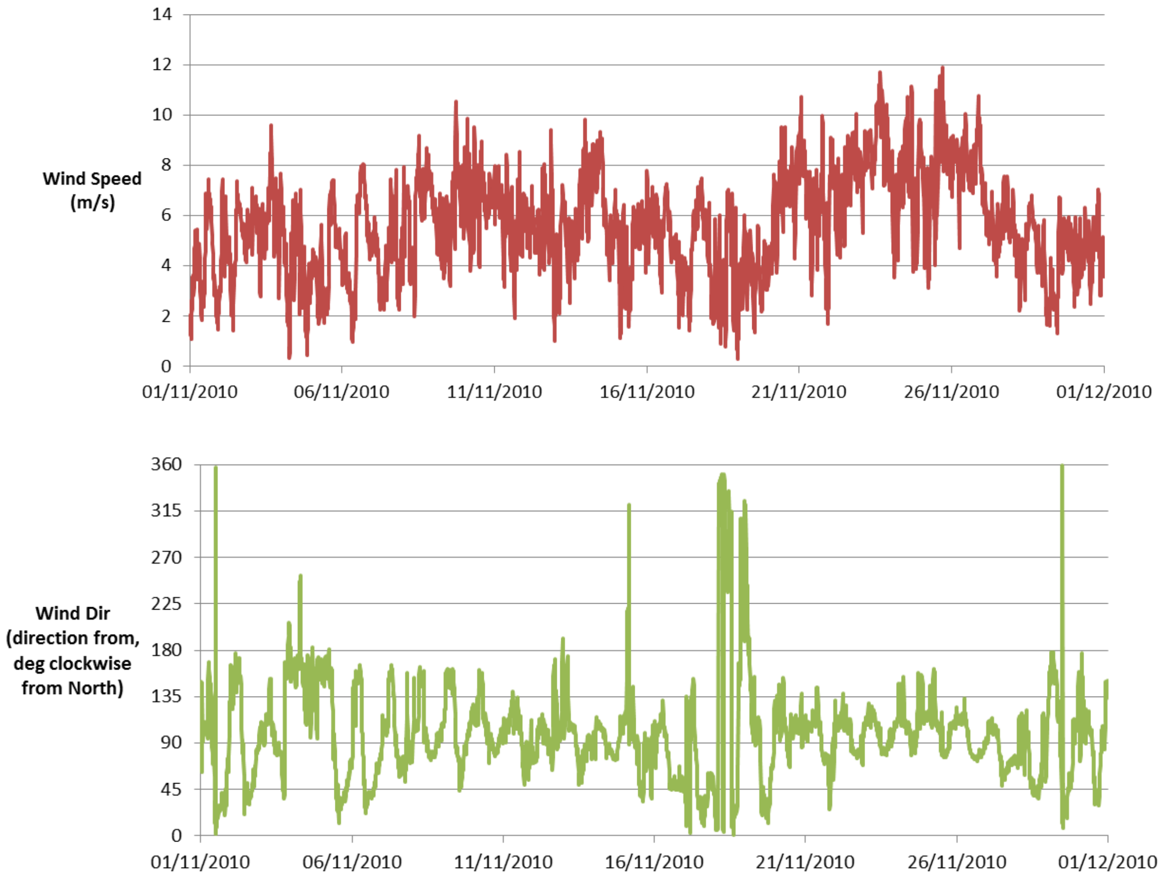


Figure 4-1 Wind Speed and Direction at the Port of Townsville During the Modelling Period (10 minute averages measured at 10 metres elevation)

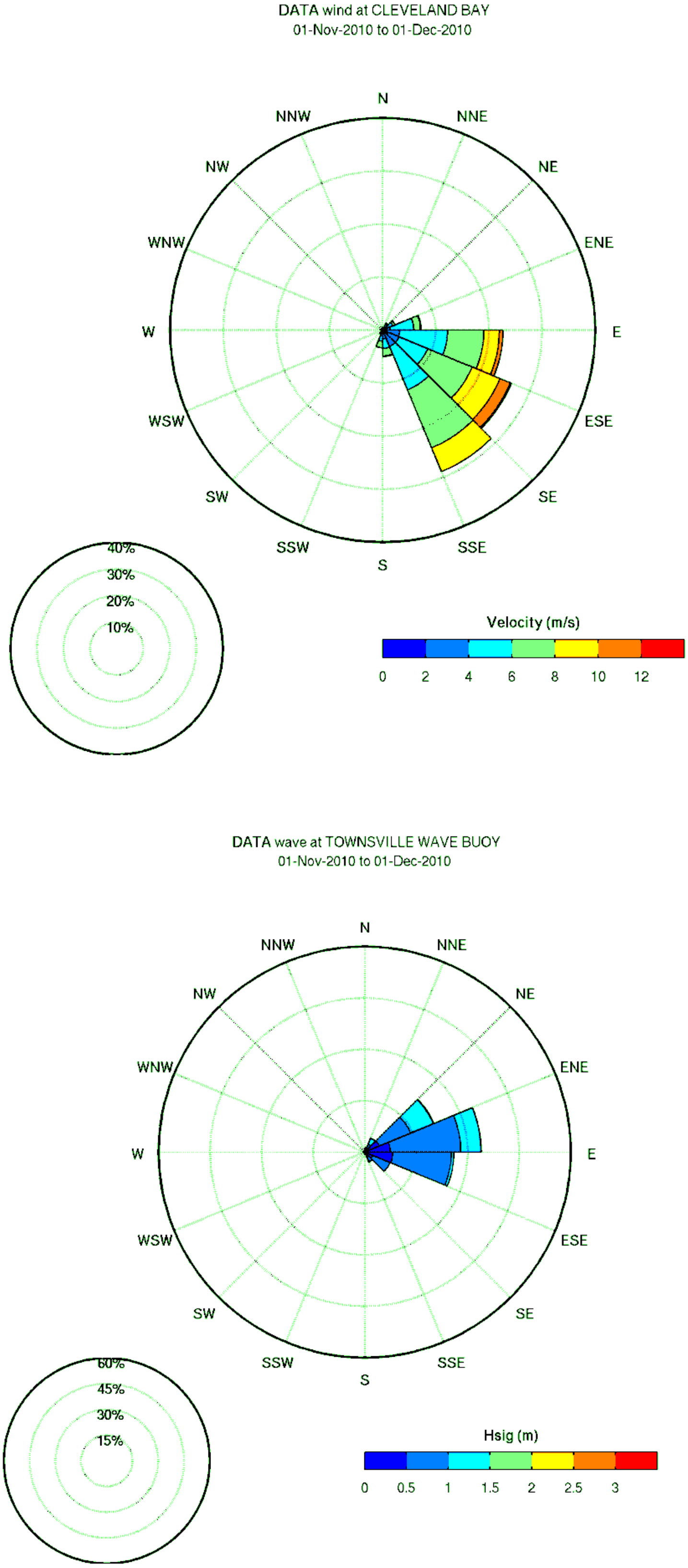
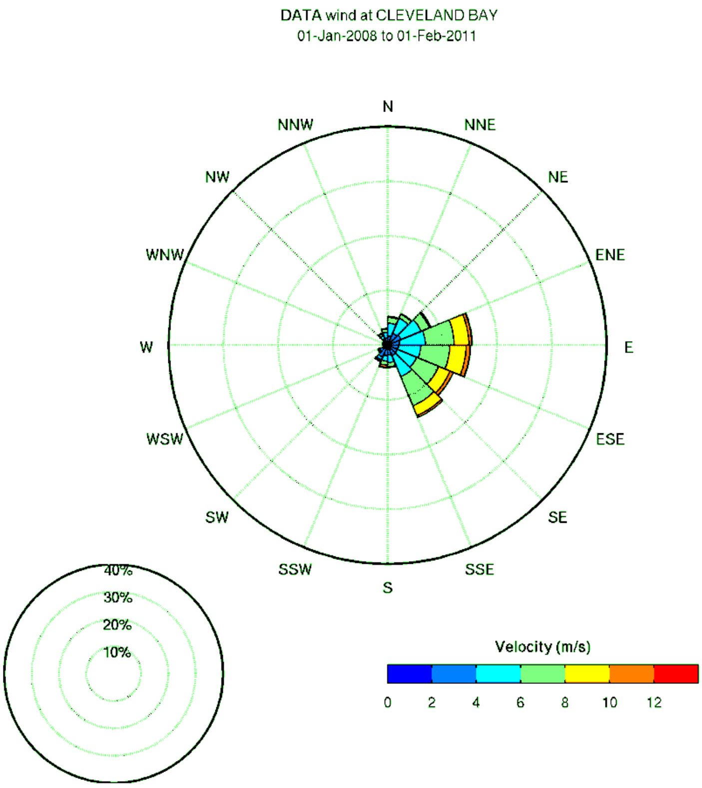


Figure 4-2 Wind (top) and Wave (bottom) Roses for the Modelling Period



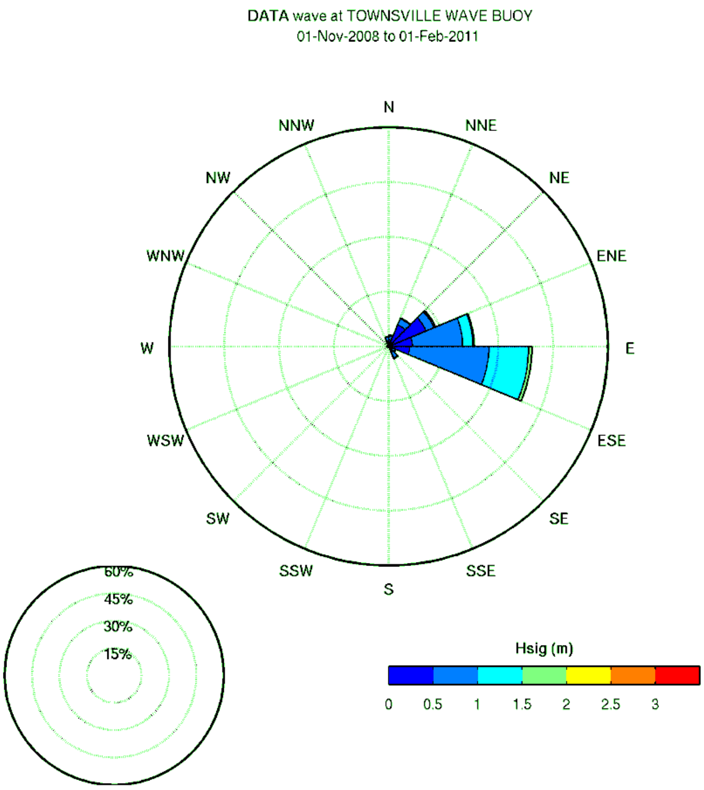


Figure 4-3 Wind (top) and Wave (bottom) Roses for the Period 2008-2011

Figure 4-4 shows the typical tidal current pattern in Cleveland Bay during low-wind spring tidal conditions. The flow can be seen to be predominantly in a south-west (flooding) to north-east (ebbing) direction.

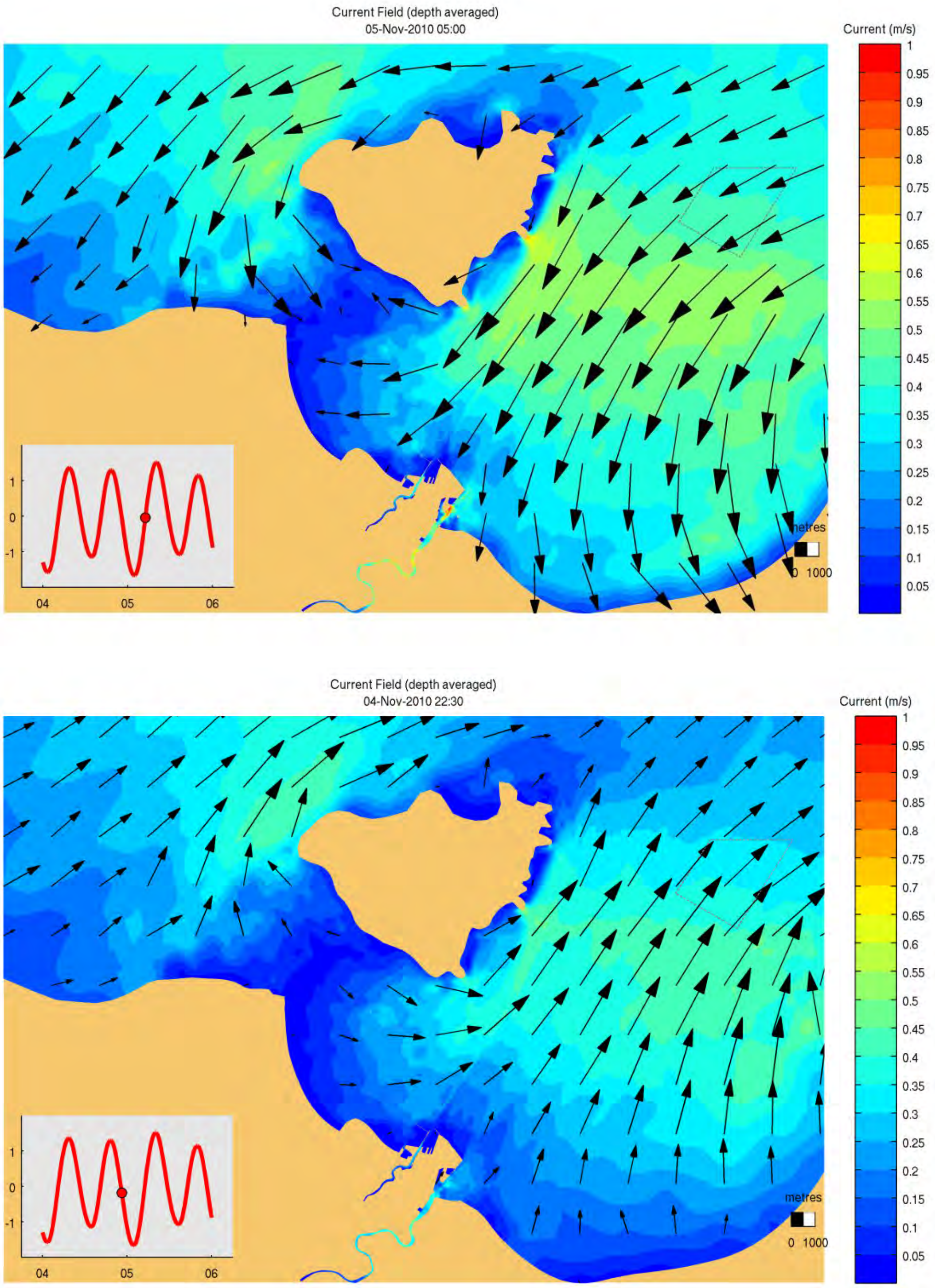
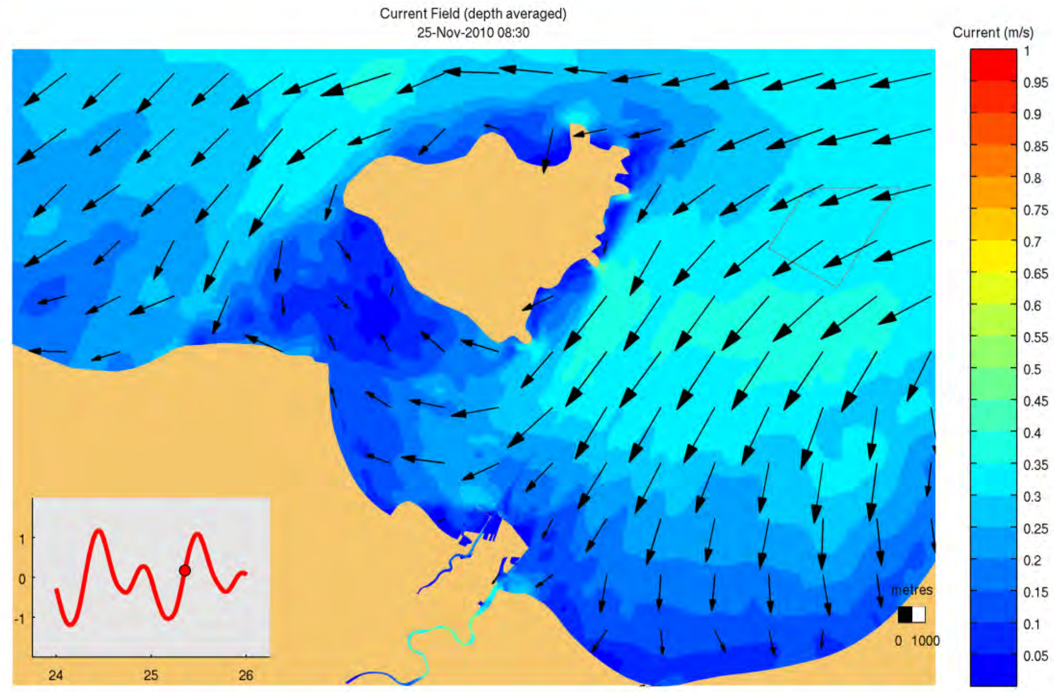


Figure 4-4 Typical Tidal Current Flow Pattern in Cleveland Bay: Flood Tide (top) and Ebb Tide (bottom)

Figure 4-5 shows the effects of relatively strong south-east wind conditions on the flood and ebb tide current patterns. The major difference from the no-wind pattern is the relatively strong ebb tide flow driven to the north-west between Cape Pallarenda and Magnetic Island.



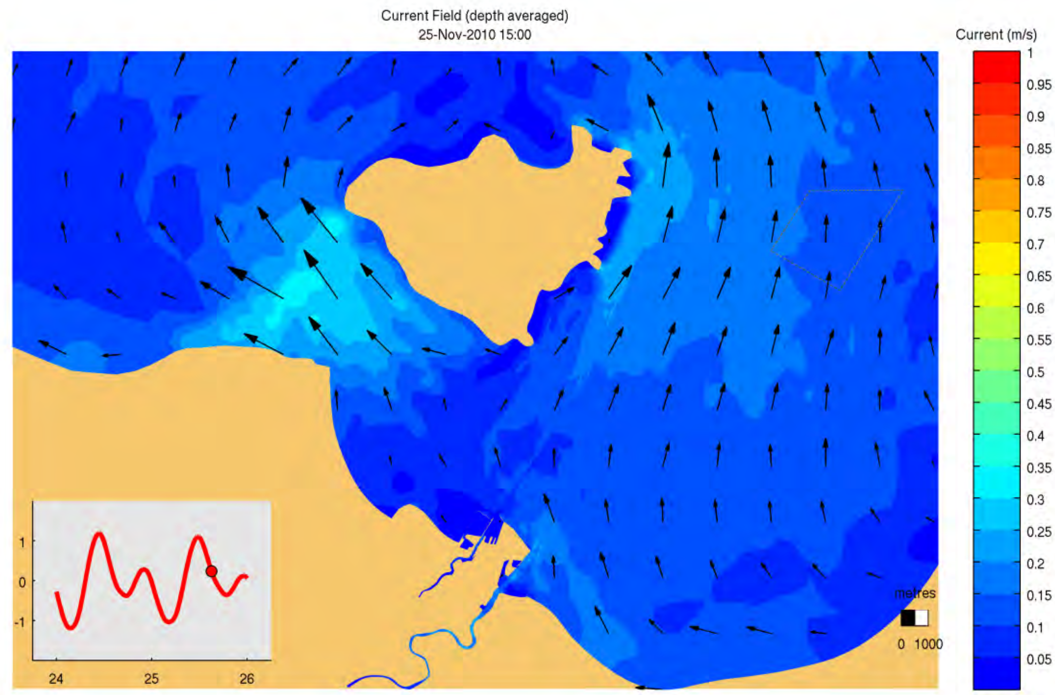


Figure 4-5 Influence of Prevailing Wind Forcing on Current Patterns: Flood Tide (left) and Ebb Tide (right)

The residual depth-averaged currents for the simulated period are shown below in Figure 4-6 which again shows the net effect of the ebb-tide flow to the north-west at Cape Pallarenda. The wind-driven net north-west drift in the Great Barrier Reef lagoon offshore of Cleveland Bay can also be seen.

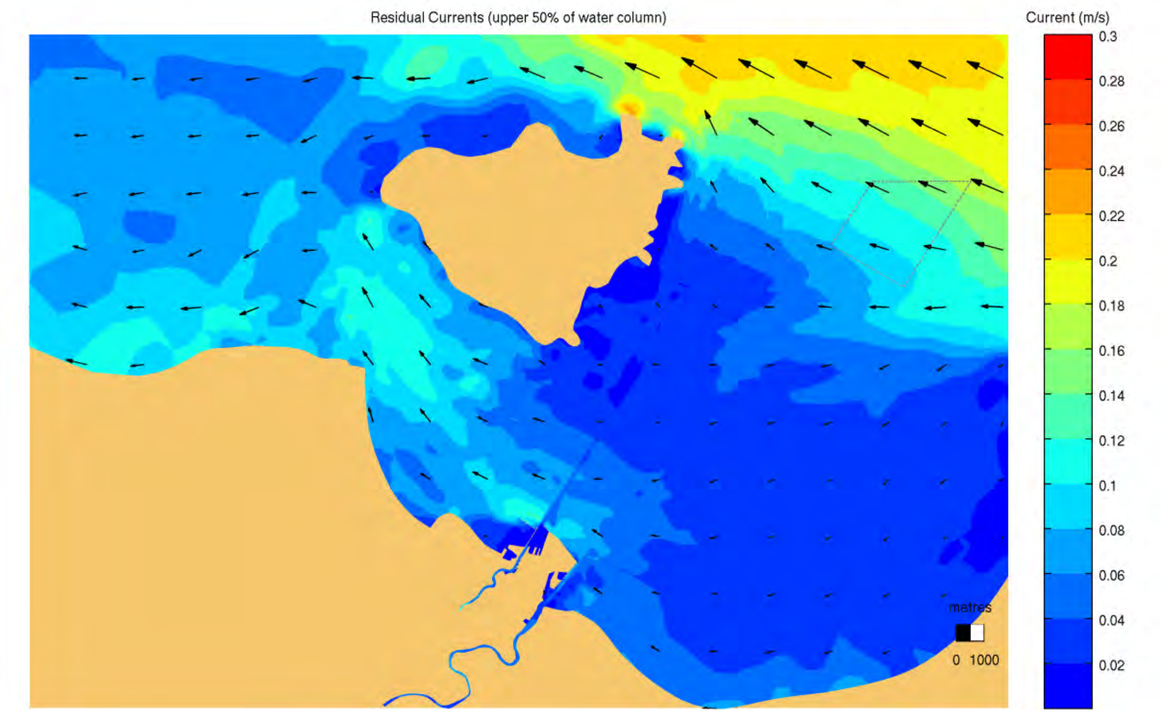


Figure 4-6 Typical Residual Depth-Averaged Current through Cleveland Bay due to Prevailing Winds from the Southeast

4.2 Hydrodynamic Impact Scenarios

Various bathymetric configurations and reclamation phases were considered in the hydrodynamic modelling scenarios based on the proposed staging of the development. The three scenarios assessed included a Base Case (representative of conditions prior to commencement of the port expansion), an Interim Case (at the conclusion of Stage 1 development), and an Ultimate Case (at the conclusion of Stage 2 and 3 development), as described here:

(1) Base Case. This included all dredging and reclamation associated with the Marine Precinct;

(2) Interim Case. This included the widened channel, the dredging of Berth 12, and the interim reclamation area proposed as part of Stage 1; and

(3) Ultimate Case. This included full dredging of the constructed harbour, the final reclamation configuration and deepening of the approach channel to -13.5mLAT (-15.4mMSL).

Model layouts for these scenarios are shown in Figure 4-7 to Figure 4-9.

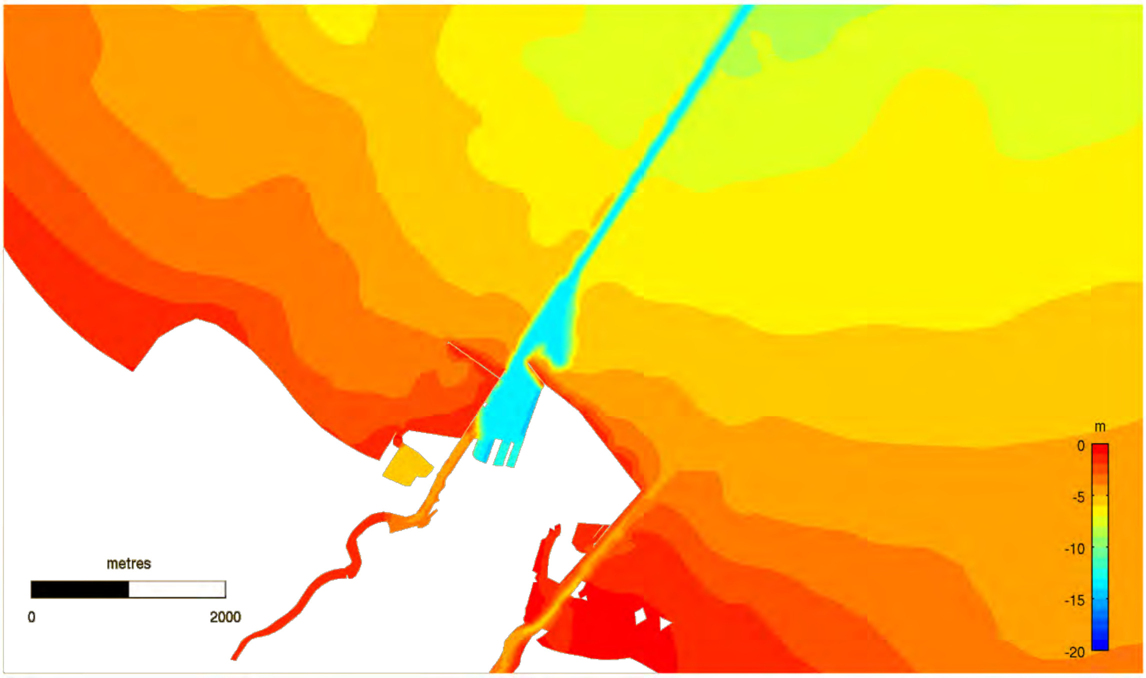


Figure 4-7 Base Case Model Bathymetry

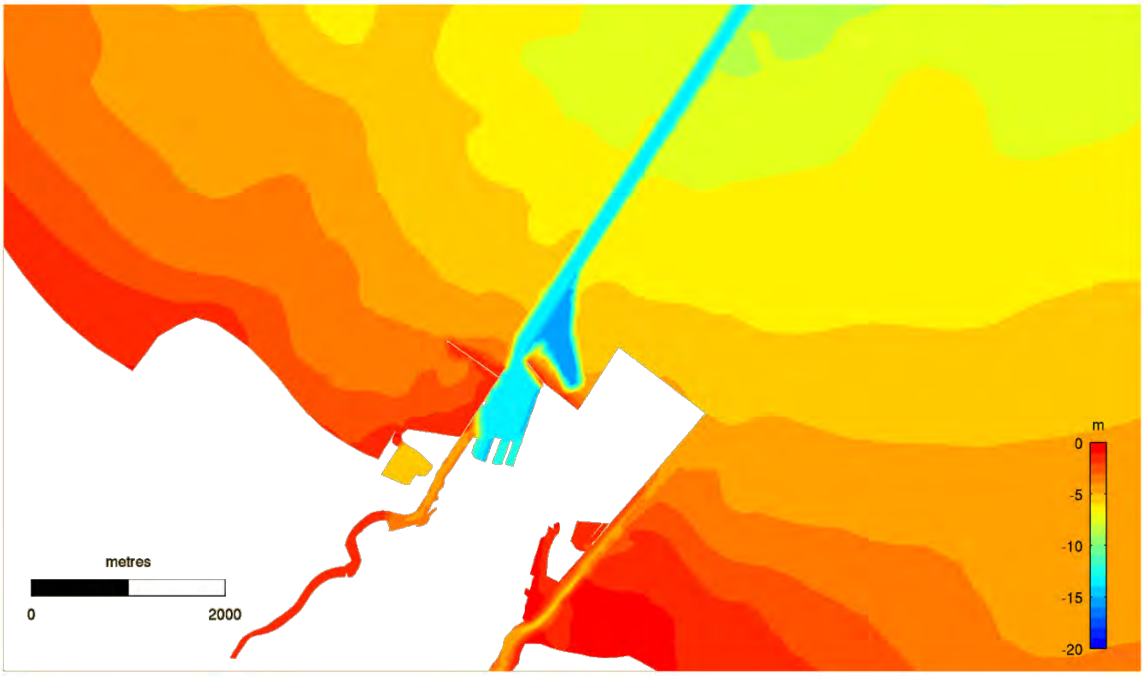


Figure 4-8 Interim Case Model Bathymetry

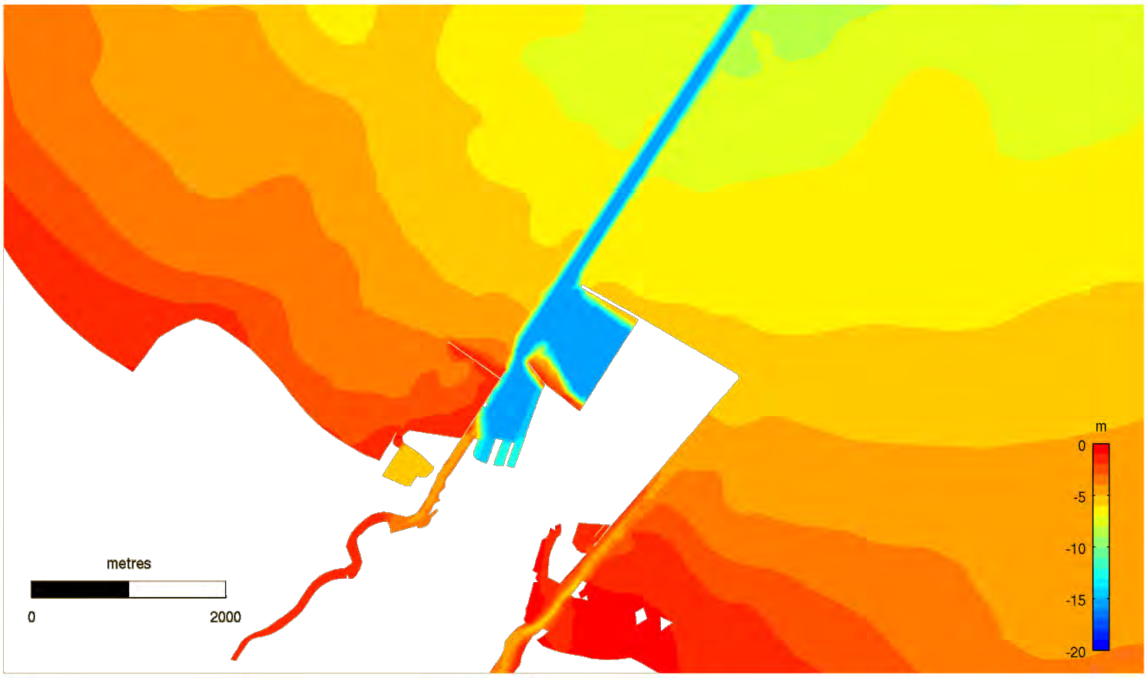


Figure 4-9 Ultimate Case Model Bathymetry

For impact assessment purposes the model was run from 1/01/2013 to 1/02/2013, a period which included predominantly easterly winds and a period of significantly large spring tides. Hydrodynamic impacts were assessed by comparing the Interim Case and Ultimate Case with the Base Case.

4.3 Hydrodynamic Modelling Results and Discussion

Results are presented below in term of hydrodynamic impact at specific times between the Base Case and Interim configuration, and the Base Case and Ultimate configuration. Figure 4-10 illustrates the tide level near the port for the simulation and the times at which the typical current patterns and impacts have been extracted. These tidal conditions correspond to peak ebb and flood flows during a period with a large spring tidal range.

Spatial plots of the changes in velocity magnitudes between the Base Case and Interim Case are shown in Figure 4-11 and Figure 4-12, and between the Base Case and Ultimate Case in Figure 4-13 and Figure 4-14. Spatial water level impact plots are not shown due to the negligible magnitude of the changes.

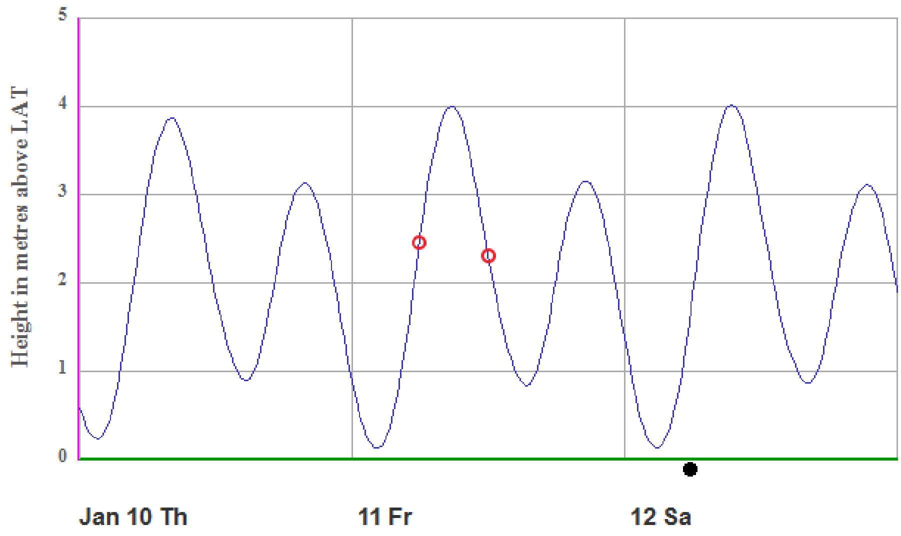


Figure 4-10 Hydrodynamic Impact Assessment Tide Levels
Flood: 06:00 11/01/2013 Ebb: 12:00 11/01/2013

Figure 4-11 illustrates the difference in velocity in the Interim Case compared to the Base Case during a flooding spring tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The velocities to the north, west and south of the interim reclamation area are reduced by up to 0.15 m/s. There are increases in velocity of up to 0.2 m/s relative to the Base Case to the east of the interim reclamation area due to the diversion of tidal flows around the reclamation area. Negligible velocity changes are predicted to occur in the Ross River entrance channel adjacent to the Marine Precinct.

Figure 4-12 illustrates the difference in velocity in the Interim Case compared to the Base Case during an ebb tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The velocities to the north of the interim reclamation are up to 0.07 m/s lower in the Interim Case than in the Base Case. There are increases in velocity of up to 0.03 m/s relative to the Base Case to the east of the proposed interim reclamation due to the diversion of tidal flows around the reclamation area.

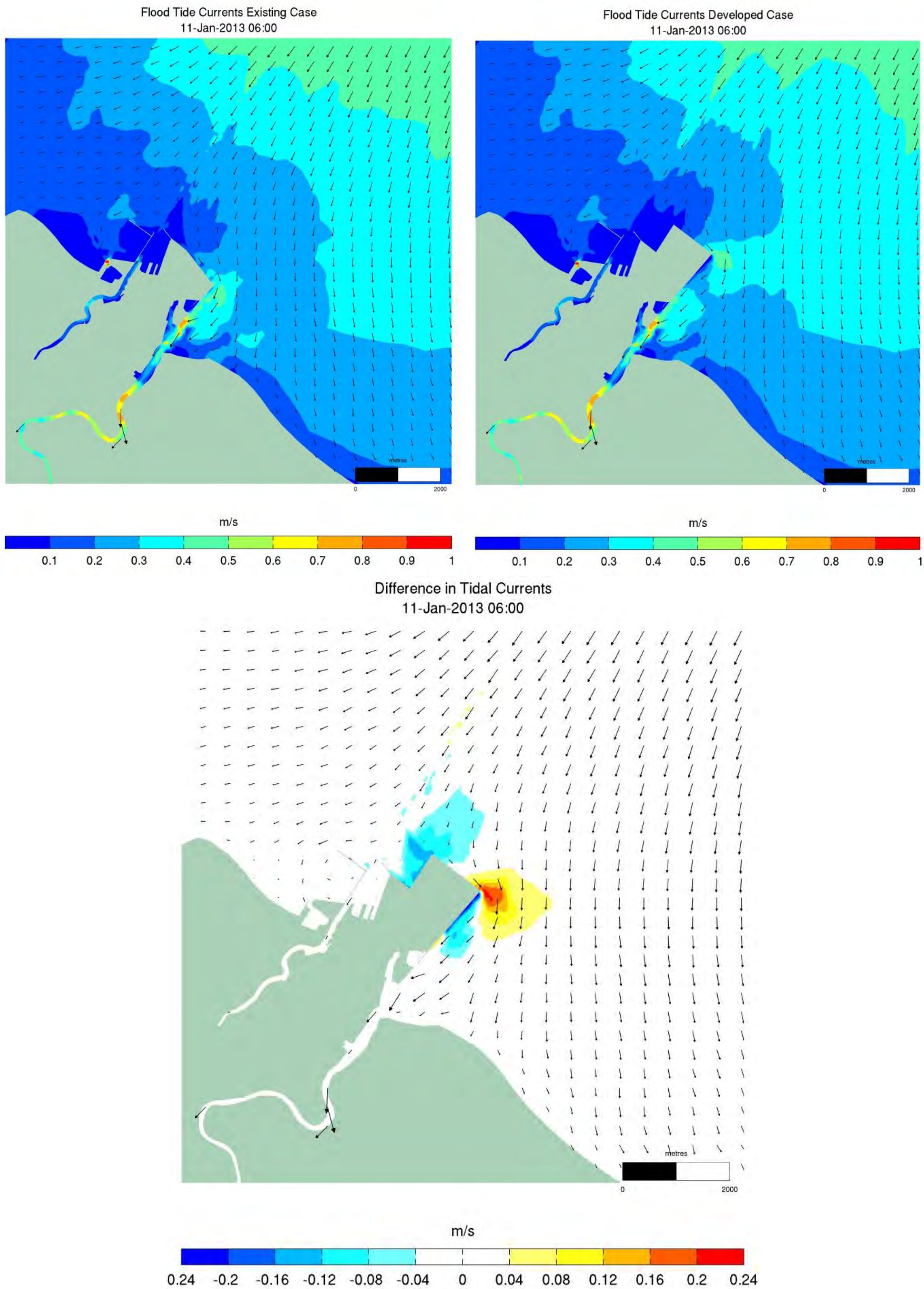


Figure 4-11 Flood Tide Velocity – Base Case (Top Left), Interim Case (Top Right) and Difference (Bottom)

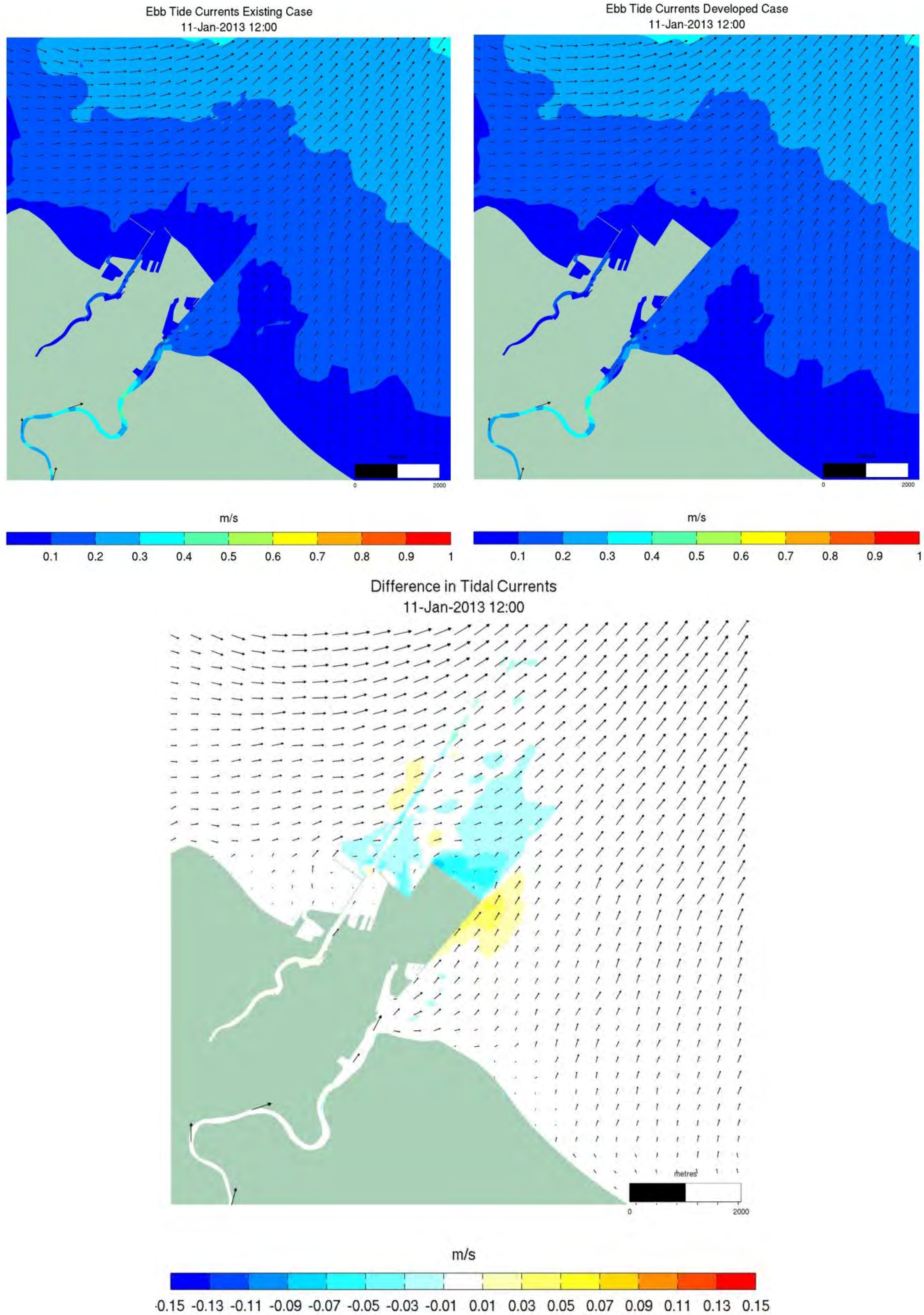


Figure 4-12 Ebb Tide Velocity – Base Case (Top Left), Interim Case (Top Right) and Difference (Bottom)

Figure 4-13 illustrates the difference in velocity in the Ultimate Case compared to the Base Case during a flooding spring tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The velocities to the north of the new north-eastern revetment are reduced by up to 0.15 m/s. Velocities within the new port expansion harbour area are up to 0.2m/s lower than the Base Case due to the increases in depth and sheltering by breakwaters. There are increases in velocity of up to 0.25 m/s relative to the Base Case to the east of the proposed port expansion due to the diversion of tidal flows around the reclamation area. The Ross River approach channel will continue to experience flood tide cross-currents at the tip of the reclamation, which will be shifted further offshore under the Ultimate Case but will remain of a similar magnitude to the Base Case. Negligible velocity changes are predicted to occur in the Ross River entrance channel adjacent to the Marine Precinct.

Figure 4-14 illustrates the difference in velocity in the Ultimate Case compared to the Base Case during an ebb spring tide. Reductions in velocity magnitude are in blue, and increases in yellow / red. The velocities to the north of the new north-east breakwater are up to 0.07 m/s lower in the Ultimate Case than in the Base Case. Velocities within the new port expansion harbour area are up to 0.1 m/s lower than the Base Case due to the increases in depth and sheltering by breakwaters. There are increases in velocity of up to 0.05m/s relative to the Base Case to the east of the proposed port expansion due to the diversion of tidal flows around the reclamation area.

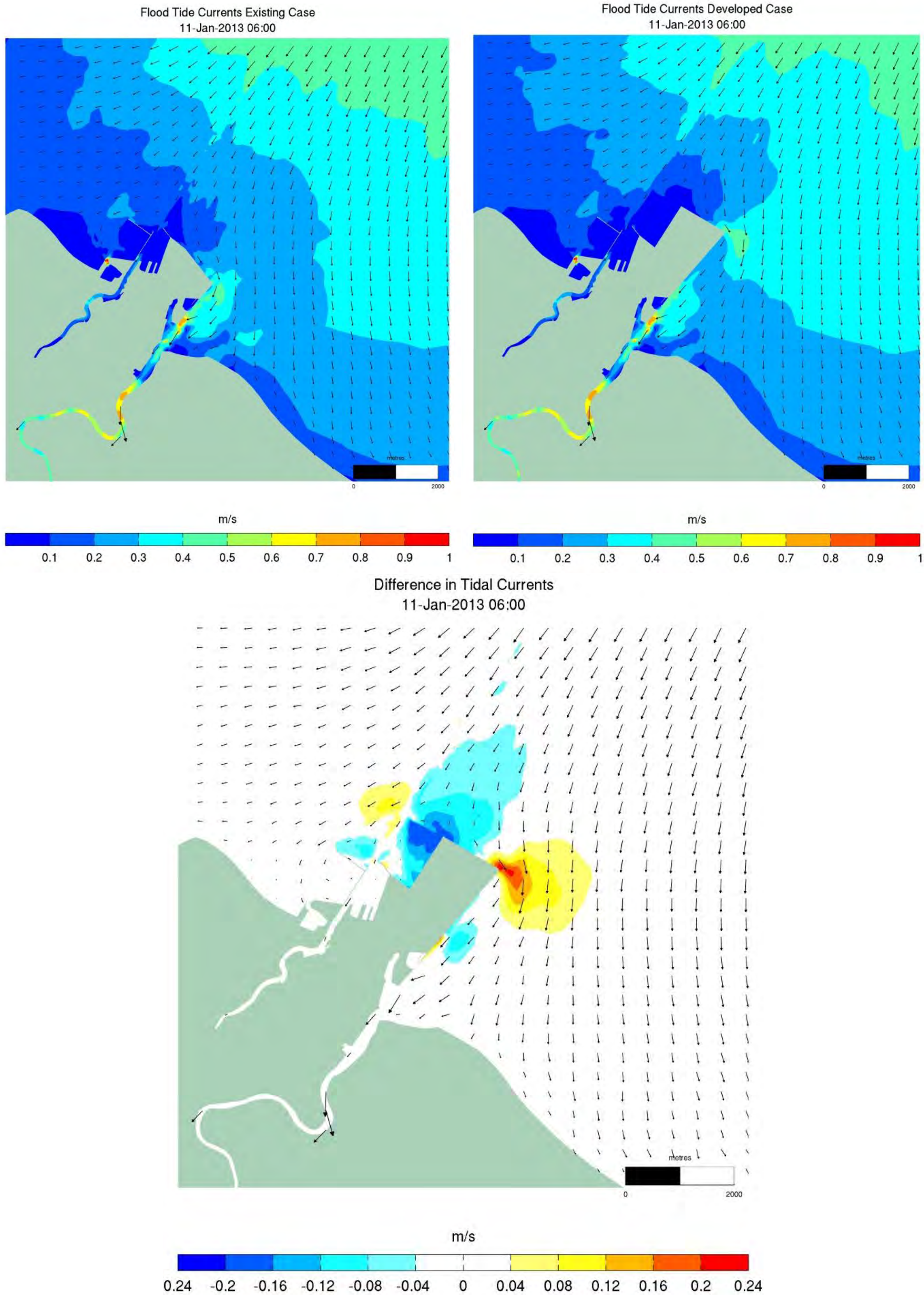


Figure 4-13 Flood Tide Velocity – Base Case (Top Left), Ultimate Case (Top Right) and Difference (Bottom)

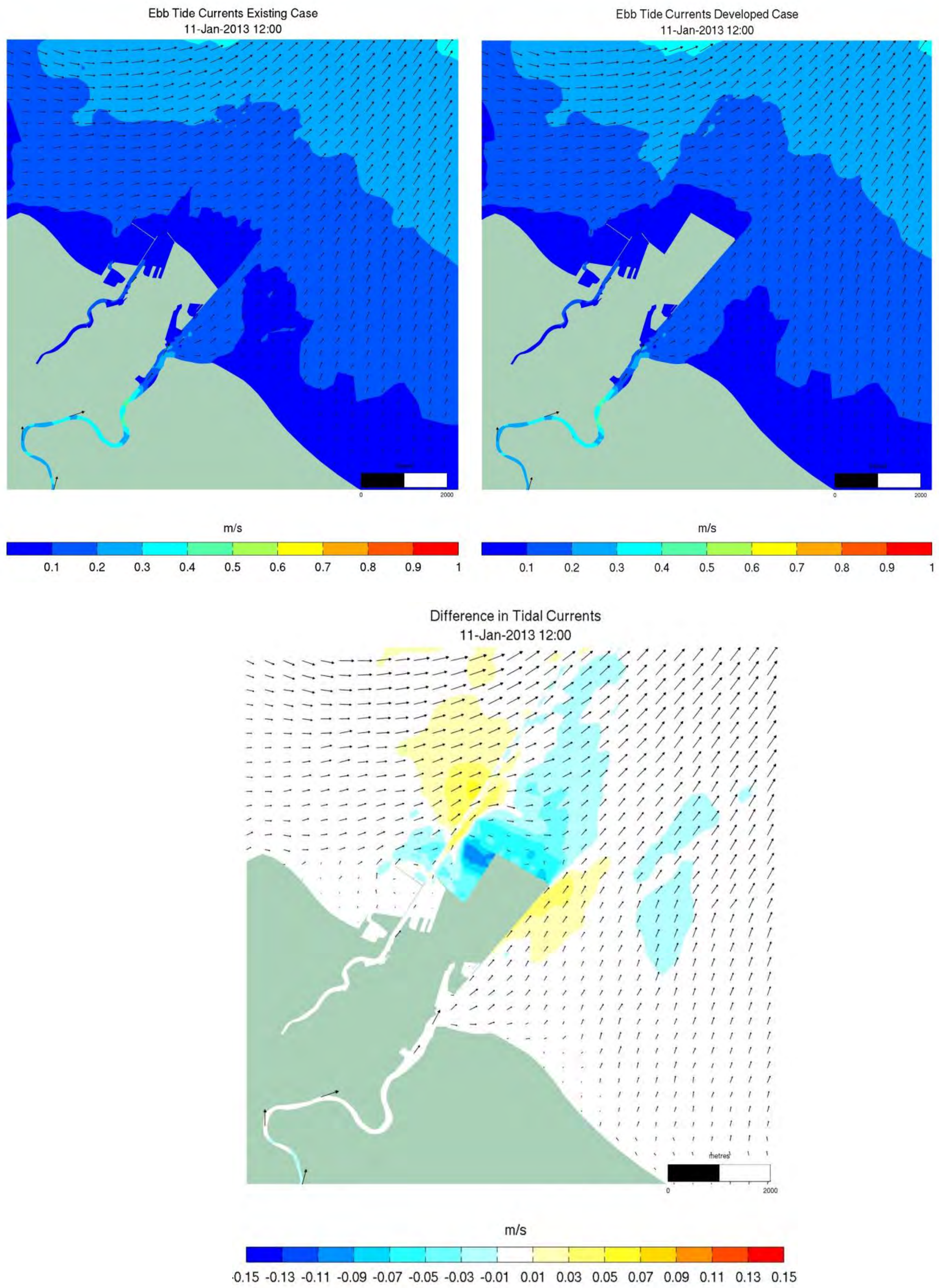


Figure 4-14 Ebb Tide Velocity – Base Case (Top Left), Ultimate Case (Top Right) and Difference (Bottom)

Water level percentiles derived from the model at the Townsville Storm Tide Gauge for the Base Case and Ultimate Case are shown in Figure 4-15. No change in water levels is predicted for the ultimate port expansion development case relative to the Base Case. The model results indicate that no water level impacts will occur at any location due to the port expansion development.

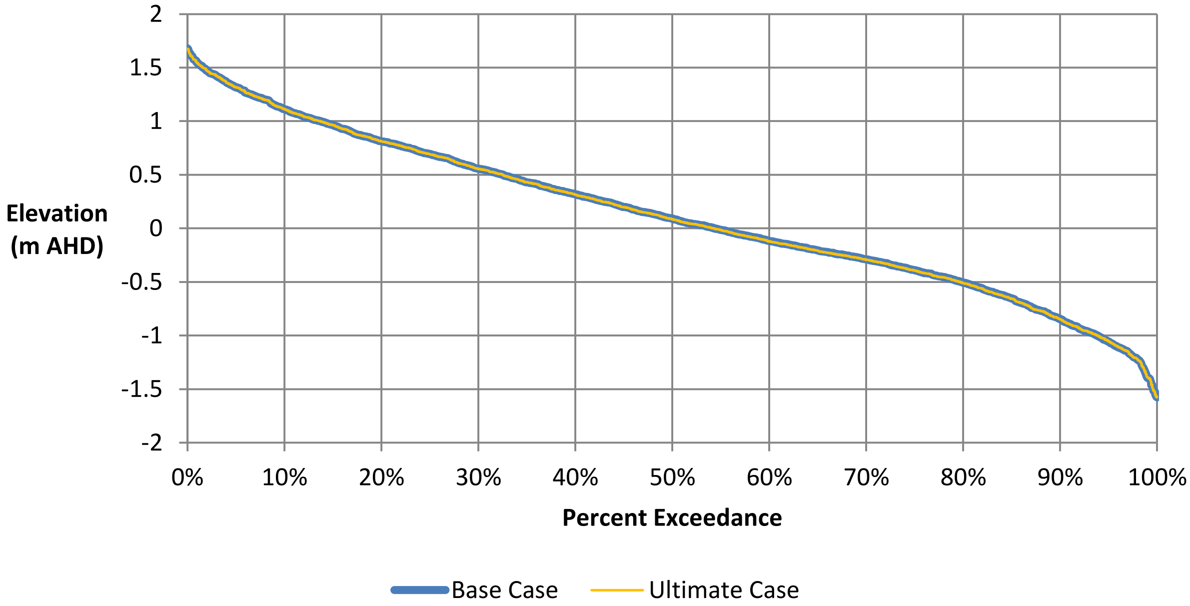


Figure 4-15 Water Level Exceedance Plot at the Townsville Storm Tide Gauge for the Base Case and Ultimate Case

Figure 4-16 illustrates the change in velocity magnitude adjacent to the port reclamation area for the Ultimate Case compared to the Base Case. The two locations that are compared are shown as Point 1 and Point 2 in the top panel of Figure 4-16. This provides a direct comparison between the expected currents adjacent to the existing and future breakwaters. It is noted that a significant increase in spring tide velocities is expected in the Ultimate Case compared to velocities adjacent to the existing breakwater. Morphological impacts driven by these velocity changes are considered in Section 5. In general the current velocity changes are unlikely to create any additional problems for ship navigation.

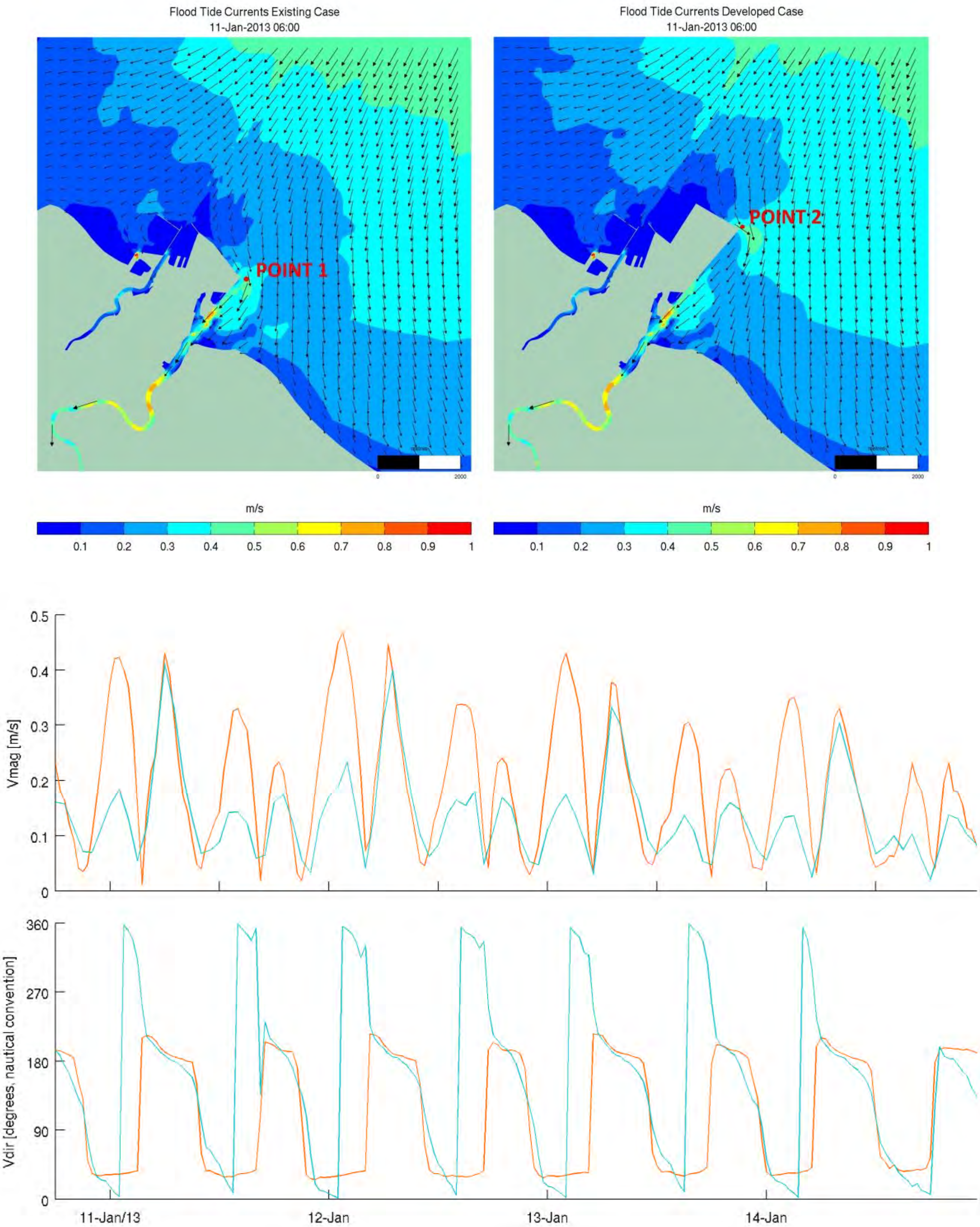


Figure 4-16 Velocity Magnitude Time Series at Point 1 in the Base Case and Point 2 in the Ultimate Case (Base Case in Blue, Ultimate Case in Red)

4.5 Summary of Hydrodynamics Results

The hydrodynamic impacts of the proposed port expansion are not large in magnitude or extent, being confined to changes in velocity magnitude in the immediate vicinity of the proposed breakwaters and reclamation area. Water levels at all locations in the vicinity of the proposed works will not change as a result of the Project.

Velocity magnitudes decrease by up to 0.25 m/s adjacent to the new breakwater structures and within the port expansion harbour area on both the flood and ebb tides in the Ultimate Case. There are increases in velocities of up to 0.3 m/s in the Ultimate Case in some areas as shown in Figure 4-13 and Figure 4-14. No significant change in tidal current velocities is predicted in the existing Inner Harbour in the Ultimate Case port expansion scenarios considered in these assessments.

5 Cleveland Bay Morphology and Sedimentation

5.1 General Effects

The proposed PEP will alter the bathymetry and hydrodynamics in some parts of Cleveland Bay in the vicinity of the Port such that the local sedimentation processes will be altered to a significant extent. Impacts on sedimentation processes and the marine seabed morphology relate predominantly to:

- Effects that the reclamation and breakwater structures will have on both waves and currents and associated sediment re-suspension, transport and deposition;
- Effects that deepening and widening the channels will have on sediment deposition in those dredged areas of the marine seabed; and
- Effects that alterations of the harbour basin configuration and depths have on hydrodynamics and deposition there.

This section considers impacts of the PEP on siltation processes associated with the harbour and channels and at adjoining nearshore seabed areas (e.g. The Strand).

5.2 Sediment Transport

In the context of determining impacts on sedimentation processes, including siltation rates in the harbour and shipping channels, the TUFLOW FV model was used to simulate the re-suspension of fine material due to the action of waves and currents for the Base Case and Ultimate Case to determine the potential impact of the project on bed morphology and siltation rates. The model was run for the period 01/01/2013 to 01/06/2013 for the purposes of the impact assessment.

Residual sediment transport rates were calculated by averaging results over a period of approximately 1 month, ensuring that the start and end points both coincided with similar high tide levels. It is acknowledged that the long-term residual may differ from the values derived over this limited time period, however the selected period was adopted based on being reasonably representative of prevailing climatic conditions and should not therefore be grossly different from the longer term residual. In the longer term, cyclones also have a significant influence on the distribution of sediments.

The Base Case residual suspended sediment transport patterns are shown in Figure 5-1, which indicates a net transport in the north-west direction with highest transport rates in the shallower inshore parts of Cleveland Bay. A concentrated region of higher transport is shown immediately offshore of the existing port and the partial interception of the suspended sediment flux by the dredged approach channel can be inferred by the evident reduction in transport from updrift to downdrift of this feature.

The Ultimate Case residual sediment transport and corresponding impact (difference from Base Case) are shown in Figure 5-2 and Figure 5-3 respectively. It can be seen that Outer Harbour extension will redirect the residual suspended sediment drift around the reclamation. A small net reduction in fine sediment drift from east to west of the port may occur due to the combined interception effect of the outer harbour extension and the wider and deeper Platypus channel.

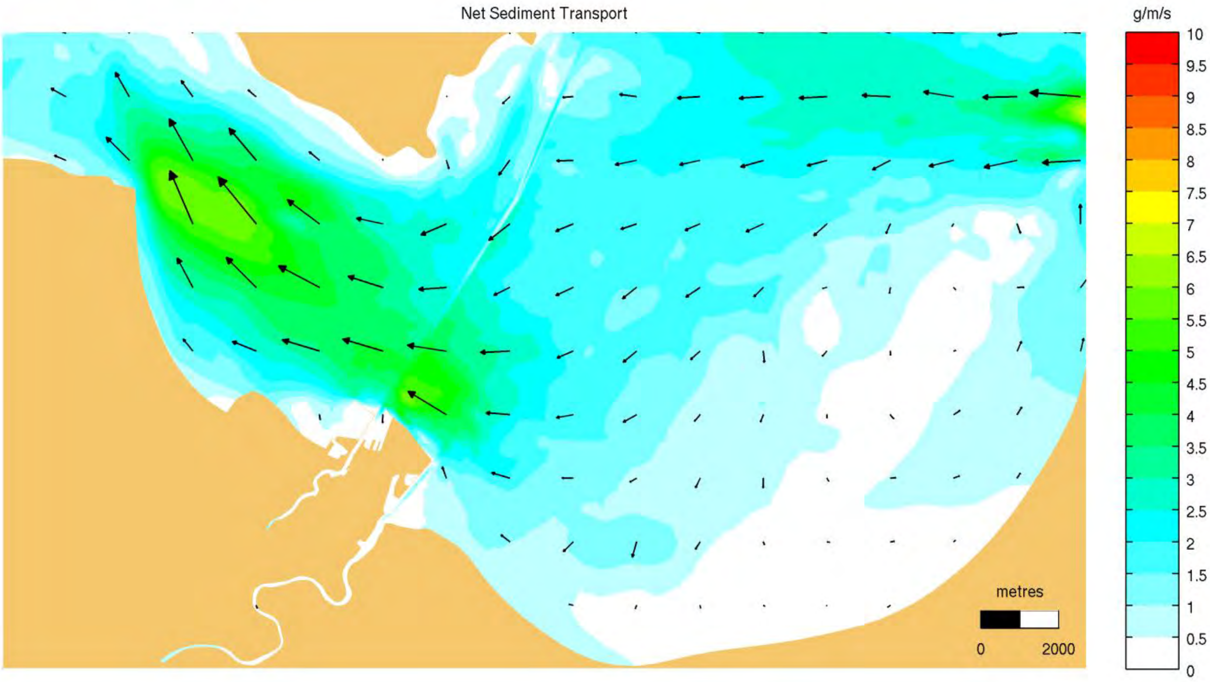


Figure 5-1 Modelled Base Case Residual Suspended Sediment Transport

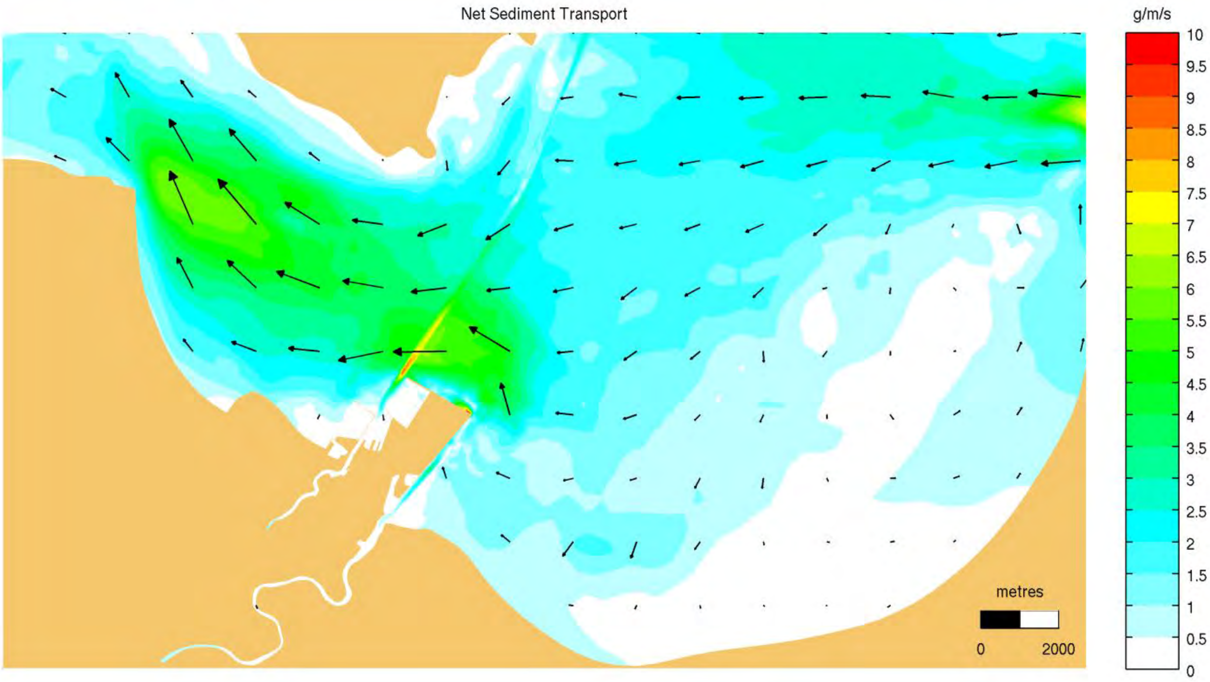


Figure 5-2 Modelled Ultimate Case Residual Suspended Sediment Transport

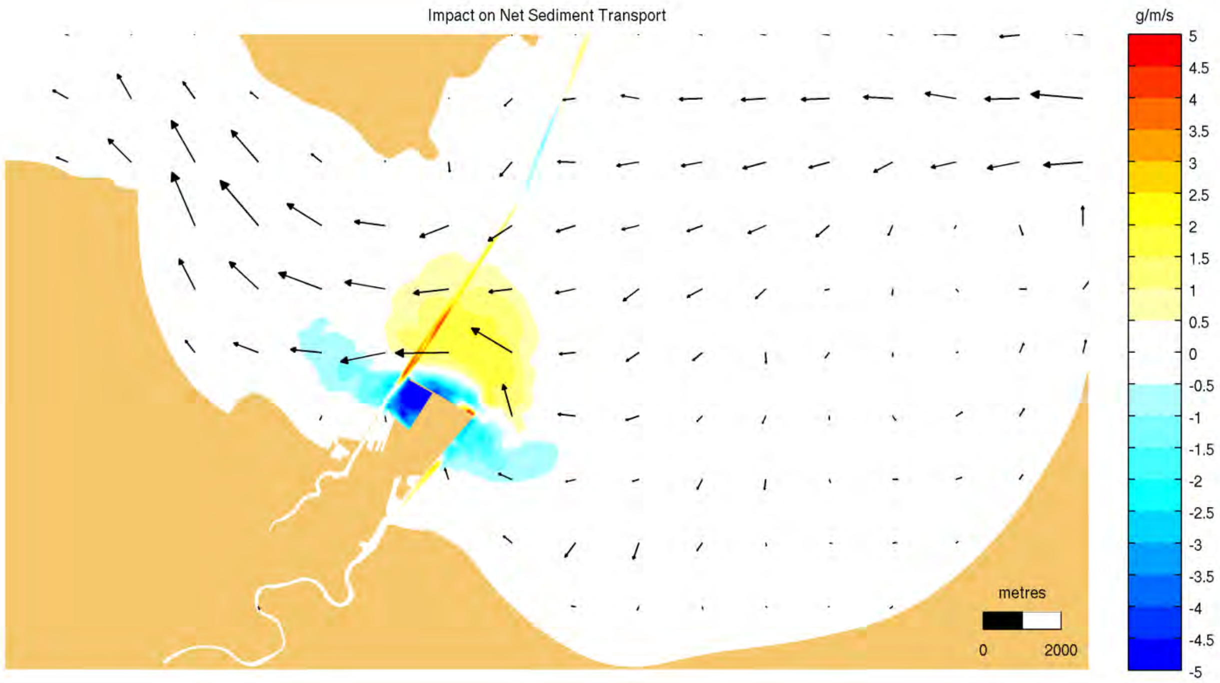


Figure 5-3 Ultimate Case Residual Suspended Sediment Transport Impacts

5.3 Channel Siltation

The modelled Base Case siltation rate in terms of bed level change in metres per year is shown in Figure 5-4 and the modelled annual siltation volumes are summarised in Table 5-1 for the regions shown in Figure 5-5. The modelled base case sedimentation rates were found to be in reasonable agreement with annual average historic dredging volumes for the existing dredged areas (POTL, 2013).

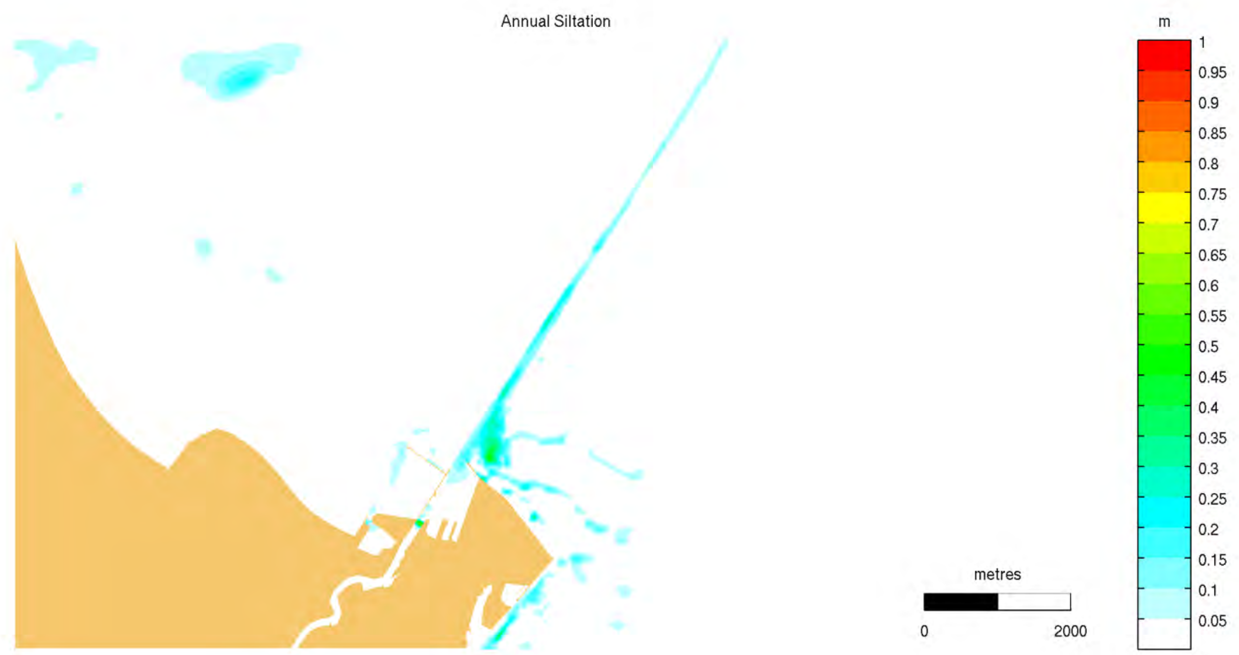


Figure 5-4 Modelled Base Case Siltation Rate (m/year)

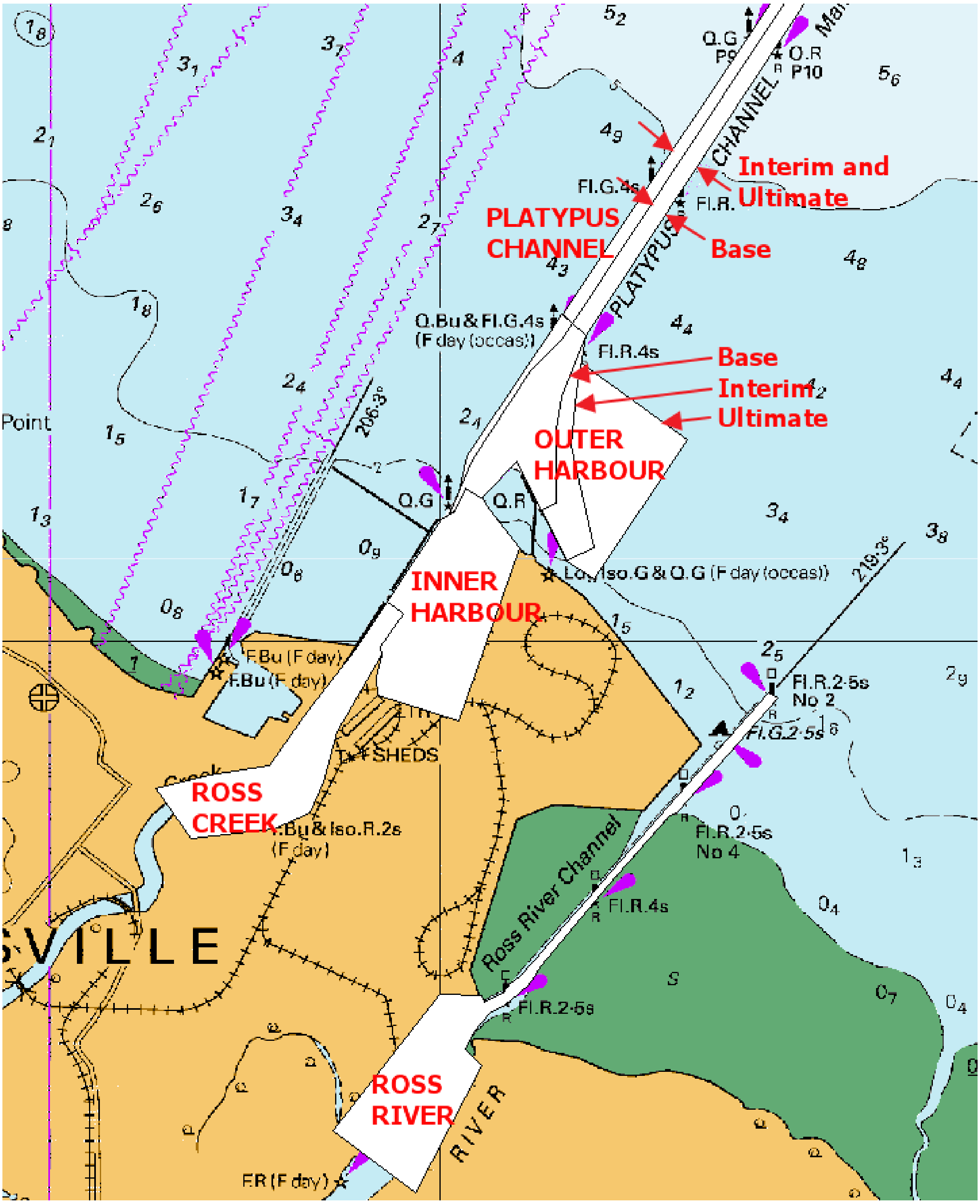


Figure 5-5 TUFLOW FV Sedimentation Model Regions

5.3.1 Interim Case

The distribution of modelled Interim Case siltation rate is shown in Figure 5-6 and the modelled annual siltation volumes for the Interim Case are summarised in Table 5-1. The changes to siltation rates due to the port expansion are shown in Figure 5-7. The model indicates a reduction in siltation rates within the inner harbour, and an increase in newly dredged areas. The model indicates an increase in siltation in most of the Platypus and Sea Channels.

Sedimentation volumes within the existing inner harbour are predicted to be reduced by around 36%. The Interim Case reclamation acts to partly reduce the magnitude of suspended sediment transport into the inner harbour dredged areas.

The annual volume of sedimentation occurring within the Platypus Channel is predicted to increase by around 20%, and by 13% in the Sea Channel. This is mainly due to the increased channel width. Sedimentation volumes within the outer harbour are predicted to increase by around 20% relative to the Base Case, primarily due to the Berth 12 dredging.

Overall, this modelling indicates that the total quantity of siltation within all of the dredged areas in the port combined may be increased by around 70,000m^3 per year (about 17% relative to the present situation). This is primarily due to the widening of the Platypus and Sea Channels.

Table 5-1 Modelled Annual Sedimentation Volumes – Interim Case (m^3)

Dredge Area	Base Case	Interim Case	Percentage Change
Dredge Area	Base Case	Interim	Percentage Change
Ross Creek	4,000	4,000	0%
Inner Harbour	28,000	18,000	- 36%
Platypus Channel	163,000	195,000	+ 20%
Sea Channel	40,000	45,000	+ 13%
Outer Harbour	128,000	153,000	+ 20%
Ross River	33,000	50,000	+ 52%
Total (modelled)	**396,000**	**465,000**	**+ 17%**

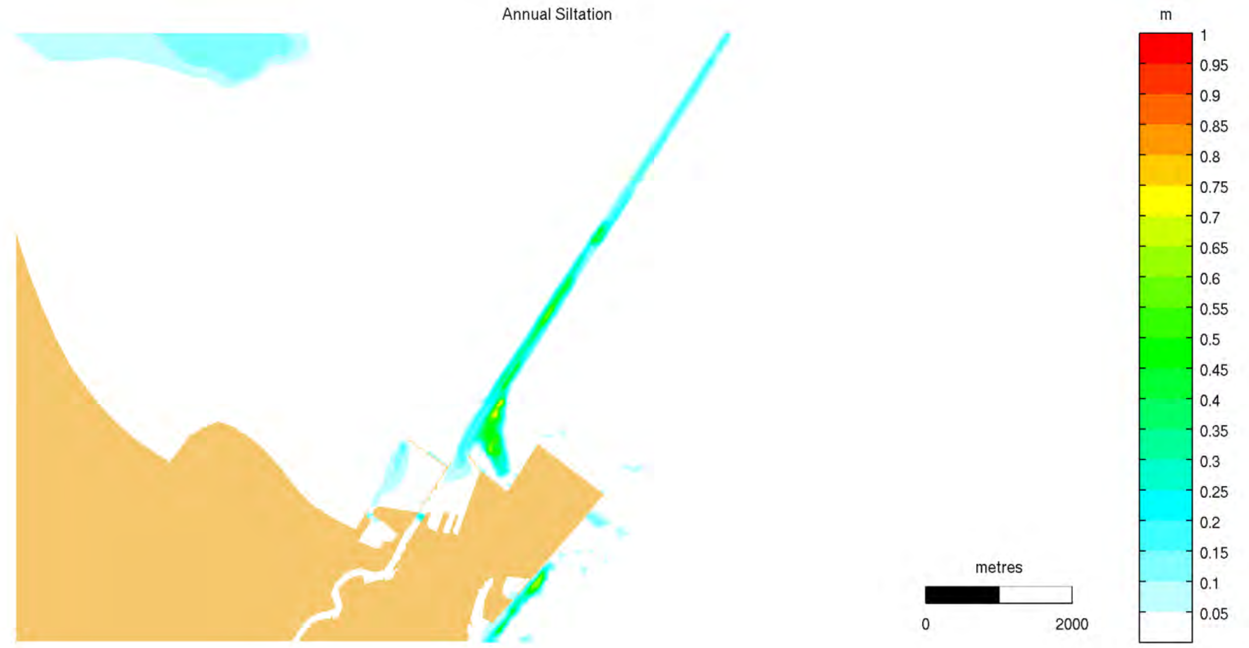


Figure 5-6 Modelled Interim Case Siltation Rate (m/year)

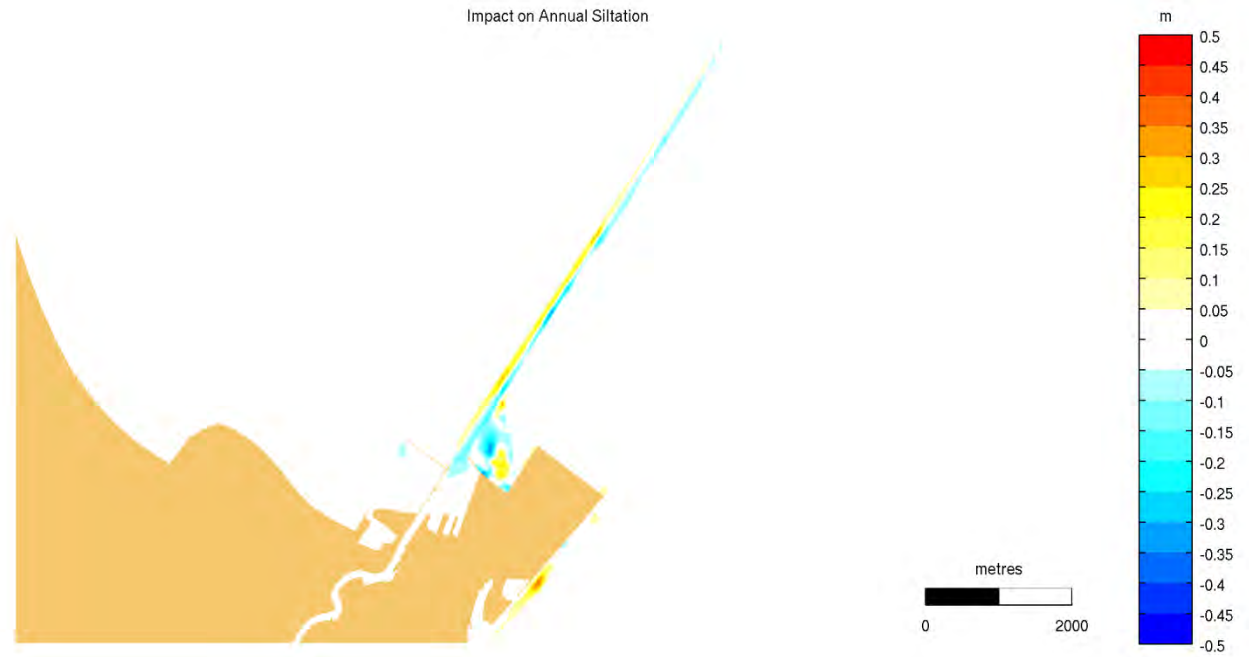


Figure 5-7 Difference in Siltation Rate between the Interim Case and Base Case (m/year)

5.3.2 Ultimate Case

The distribution of modelled Ultimate Case siltation depths is shown in Figure 5-8 and the modelled annual siltation volumes for the Ultimate Case are summarised in Table 5-2. The change in siltation rates due to the port expansion are shown in Figure 5-9. The model results indicate a reduction in siltation rates within the new enclosed outer harbour area, and an increase in siltation in the Platypus Channel and Sea Channel.

Sedimentation volumes within the existing inner harbour are predicted to be reduced by around 21% and sedimentation volumes within the outer harbour are predicted to decrease by around 15% relative to the Base Case. The Ultimate Case reclamation and breakwaters act to significantly reduce the efficiency of suspended sediment transport into the outer and inner harbour dredged areas. It should be noted that the Ultimate Case assessments have been undertaken without a western breakwater in place. A modest decrease in predicted sedimentation would most likely occur with the addition of a western breakwater.

The annual volume of sedimentation occurring within the Platypus Channel is predicted to increase by around 26%, and within the Sea Channel it is predicted to increase by around 65%. This is due to the increased channel width and depth as part of the ultimate development.

Overall, this modelling indicates that the total quantity of siltation within all of the dredged areas in the port combined will increase by around 14% relative to the present situation. Although there will be a reduced suspended sediment net transport flux around the expanded port, this is more than offset by increased siltation in the widened and deepened channel. The material depositing in the new enclosed outer harbour area will be entirely very fine silts without the minor component of coarser silt/sand that deposits in the existing dredged basin and berth areas exposed at the present time.

Table 5-2 Modelled Annual Sedimentation Volumes – Ultimate Case (m^3)

Dredge Area	Base Case	Ultimate Case	Percentage Change
Ross Creek	4,000	4,000	0%
Inner Harbour	28,000	22,000	- 21%
Platypus Channel	163,000	205,000	+ 26%
Sea Channel	40,000	66,000	+ 65%
Outer Harbour	128,000	109,000	- 15%
Ross River	33,000	46,000	+ 39%
Total (modelled)	**396,000**	**452,000**	**+ 14%**

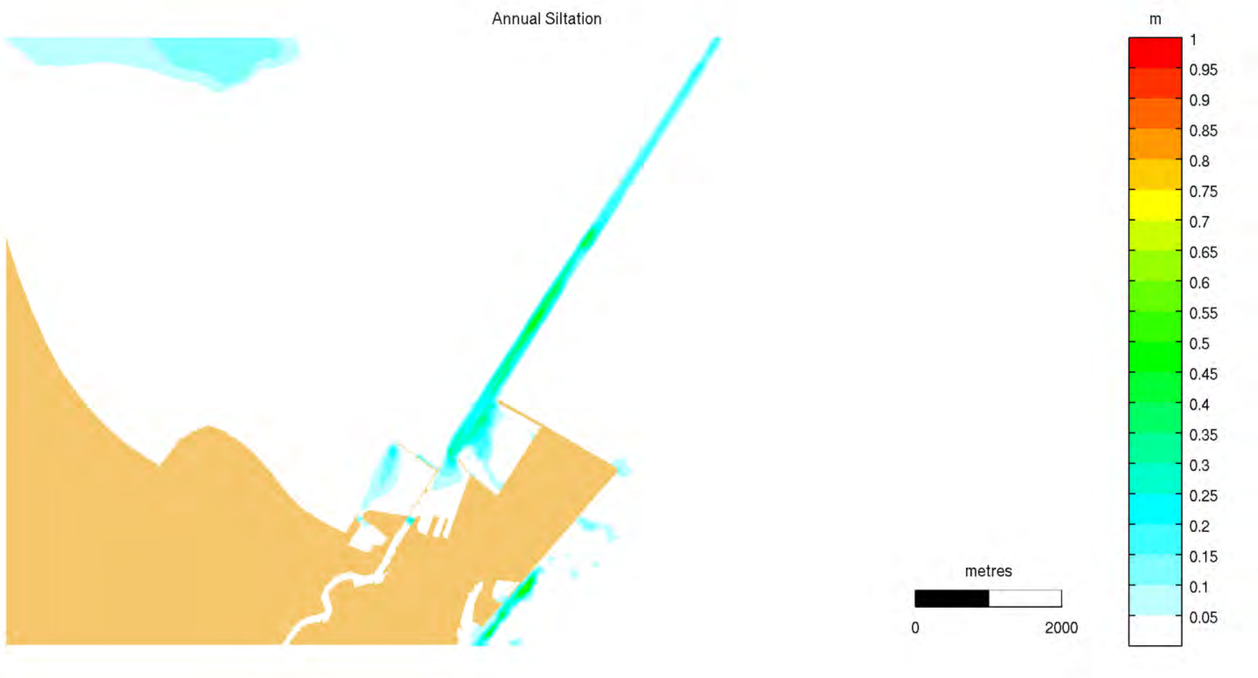


Figure 5-8 Modelled Ultimate Case Siltation Rate (m/year)

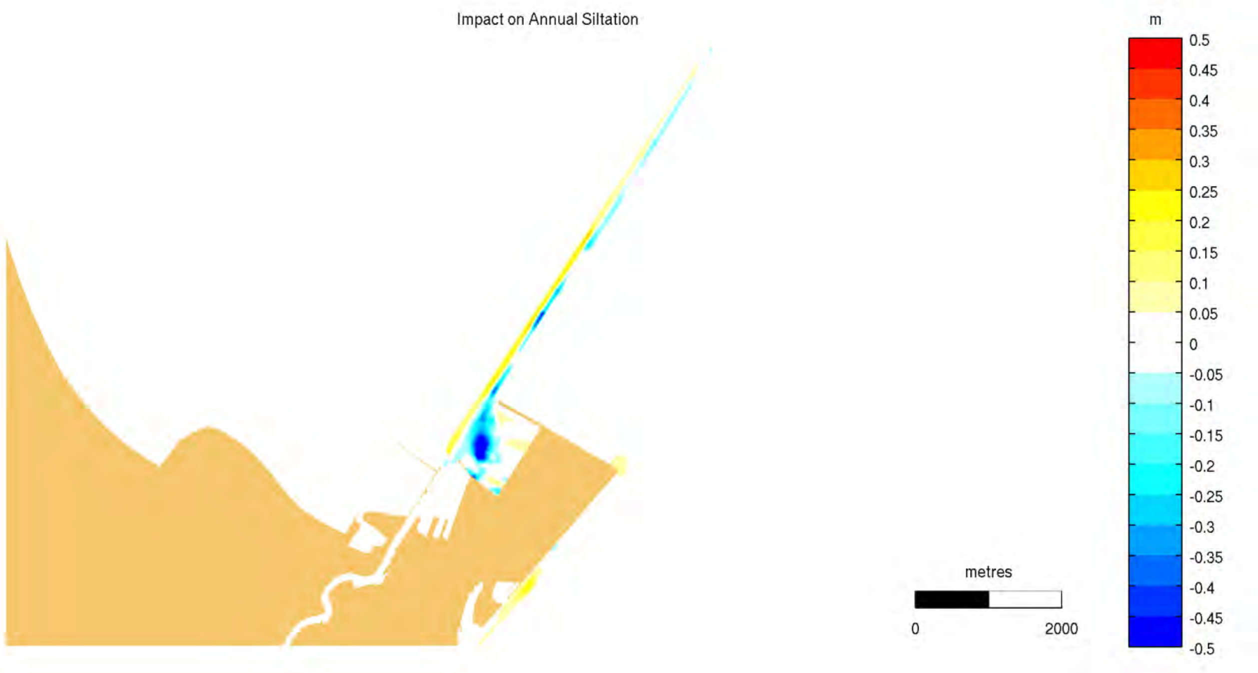


Figure 5-9 Difference in Siltation Rate between the Ultimate Case and Base Case (m/year)

5.4 Fine Fluvial Sediments from Ross River

To assess the potential for changes to siltation patterns supplied by fluvial sediment from Ross River, the TUFLOW FV model was used to investigate the fate of sediment discharged from the river in the Ultimate Case compared to the Base Case. Catchment modelling was undertaken as part of another BMT WBM study (BMT WBM, 2010) for a period of 30 years (1/4/1978 to 31/3/2008). A major inflow event in January 1998 was used for the impact assessment. The 1% exceedance level suspended sediment concentrations due to the fluvial discharge for the Ultimate Case configuration are shown in Figure 5-11. These may be compared with those for the Base Case configuration in Figure 5-10. The difference between the Ultimate and Base cases is shown in Figure 5-12.

The model results indicate that nearshore areas near The Strand are more sheltered from these suspended sediment discharges in this case and the PEP may help to reduce the amount of fine Ross River sediment that reaches and deposits in that area. There is a corresponding slight increase in the Ross River flood plume concentrations to the immediate east of the Port development.

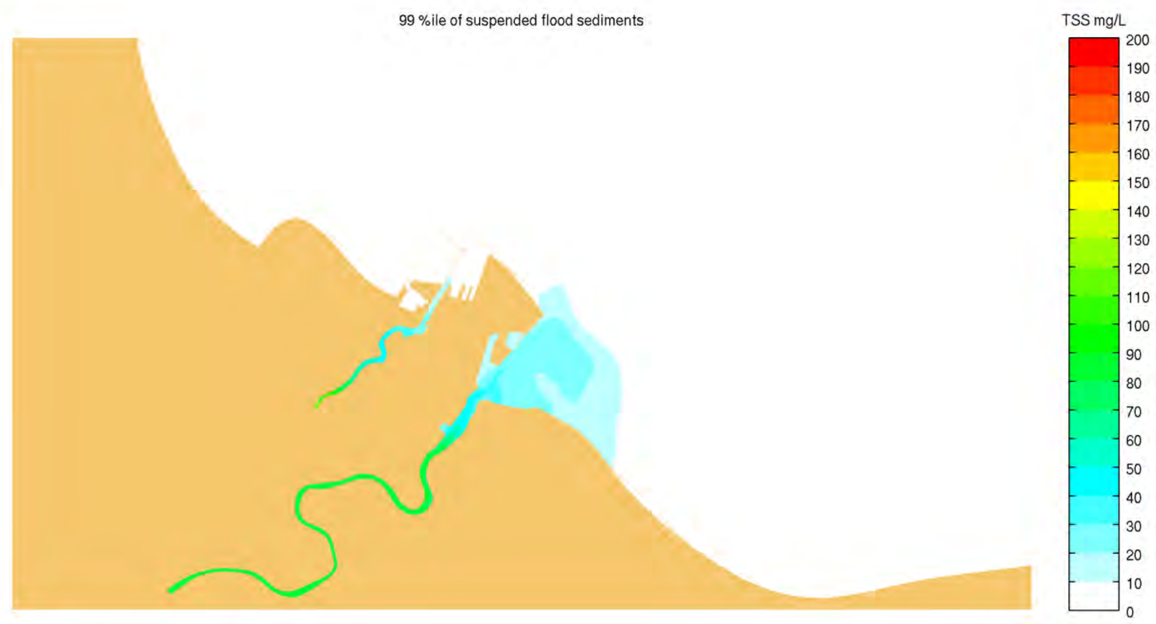


Figure 5-10 Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge in the Base Case

Figure 5-11 Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge in the Ultimate Case

Figure 5-12 Difference in Depth-Averaged TSS Exceeded for 1% of the Simulation Period due to Ross River and Ross Creek Sediment Discharge (Ultimate Case Minus Base Case)

6 Dredge Plume Assessment

6.1 Introduction

The following section describes the methodology and results of the numerical modelling assessment of the revised PEP capital dredging and reclamation programme. The revised programme involves disposal of all capital dredging material in an expanded reclamation area (no disposal of capital dredging material at sea). The dredge plume modelling methodology is described in detail followed by the presentation of model results for the following impact assessments:

- Capital program dredging assessments, including:
  - Model scenarios for Stage 1 to 3 of the revised PEP program;
  - Backhoe dredging of the berths and channel (80% of total volume);
  - TSHD channel dredging (20% of total volume);
  - Ensemble modelling scenarios for the critical (TSHD) dredging operations;
  - 'Expected' Case impacts derived as the ensemble average;
  - 'Worst Case' impacts derived as the ensemble maximum.
- Maintenance dredging assessments (for assessment of cumulative impacts).

The modelling outcomes provide a detailed and site specific assessment of possible dredge plume dispersion which was used as the basis for ecological impact assessments.

6.2 Methodology

6.2.1 Modelled Sediment Fractions

The current assessment simulated the re-suspension of "ambient" surficial seabed material as well as the "dredged" material that is released to the water column during dredging.

As summarised in Table 6-1, seven sediment fractions were simulated as part of the dredging impact assessments in order to track both the ambient and dredge material. Physical properties and model parameters were identical for corresponding size fractions of the ambient and dredge material.

The inclusion of both ambient and dredged material within the dredge plume and dispersion modelling assessment allows for the process of mixing and assimilation of the dredged material with the ambient material through the processes of re-suspension, suspended sediment transport and deposition. The ambient sediment bed was "warmed up" as described in Section 3.4. Throughout the dredge plume and dispersion assessment simulation the surface seabed sediment layer experienced re-suspension and deposition of all of the modelled sediment classes, with the relative proportions within the surface layer being dependent on the relative quantities being deposited. In this way the surface sediment layer subsequently available for re-suspension was made up of a representative mix of ambient and dredged sediments.

Table 6-1 Characteristics of Simulated Sediment Classes

Modelled Sediment Class	Still Water Fall Velocity, w_s (m/s)	Critical Shear Stress Erosion, τ_{ce} (Pa)	Critical Shear Stress Deposition, τ_{cd} (Pa)	Erosion Rate Constant, E (g/m2/s)
Ambient Clay	1 x10^{-4}	0.2	0.18	0.005
Ambient Silt	1 x10^{-3}	0.2	0.18	0.005
Ambient Siliceous Sand	1 x10^{-2}	0.2	N/A	0.05
Ambient Carbonaceous Sand	5 x10^{-3}	0.2	N/A	0.05
Dredged Material Clay	1 x10^{-4}	0.2	0.18	0.005
Dredged Material Silt	1 x10^{-3}	0.2	0.18	0.005
Dredged Material Fine Sand	3 x10^{-2}	0.2	N/A	0.05

6.2.2 Dredging Activities

The revised dredging programme involves the use of a small TSHD (similar in size to the TSHD Brisbane), and a backhoe dredge (1600kW power assumed). Approximately 20% of the total volume of dredging is anticipated to be undertaken by the TSHD, with the remaining 80% by the backhoe dredge. All material will be transported to the expanded reclamation area adjacent to the outer harbour.

The small TSHD will be used to dredge materials that can be pumped ashore from the hopper – these include soft marine sediments and dense clayey sands. The backhoe will be used to dredge the remaining material which is composed of stiff sandy clays.

6.2.3 Dredging Parameterisation

Table 6-2 presents the particle size distributions adopted for each material class, based on analysis of borehole data.

Table 6-2 Assumed Particle Size Distributions for each Dredged Material Class

	Soft marine sediments	Medium dense clayey sand	Stiff sandy clays	Tailwater discharge
Clay	40%	55%	88%	30%
Silt	50%	15%	0%	67%
Sand	10%	30%	12%	3%

Source terms for the passive plume associated with working with a TSHD are:

- The drag-head, which disturbs the bed and might re-suspend material locally;
- The propeller wash, which causes re-suspension of fines settled on or near the bed, especially when the keel clearance is limited; and
- The overflow during loading, which forms a dynamic plume from which parts are released to the surrounding waters.

The plume source terms for the TSHD were adopted as:

- Drag-head and propeller wash: 2% of the amount of fines within the dredged materials
- During overflow 80% of the fines entering the hopper disappear through the overflow. Of this 80%, approximately 85% forms a dynamic plume on the seabed in the dredging area, which will be re-cycled and 15% goes in the water column as a passive plume outside the dredging area. It is the passive plume (12% of the fines entering the hopper) which is represented in the numerical model.

The plume generation source term for a backhoe dredger is 3% of the fines within the material dredged. The production rate of the backhoe is expected to be lower during the channel deepening operation due to the thinner layer of sediment to be removed as well as the requirement to move clear of the channel for shipping movements.

The release of sediment to the water column during dredging was calculated as a percentage of the production rate, varying according to whether the dredge was operating with or without overflow. A uniform vertical distribution was assumed for all plume sources. Key parameters adopted for the dredging program are presented in Table 6-3 and Table 6-4.

Table 6-3 Key Assumptions for Plume Release Rates – Small TSHD (Equivalent Size to TSHD Brisbane)

Dredge Type	Small TSHD	
Material Class	Soft Marine Sediments	Medium Dense Clayey Sand
Assumed in-situ dry density [kg/m^3]	1450	1950
Production/trip [in-situ m^3]	1580	1800
Hopper volume [m^3]	2900	2900
Release rate of sediment to the water column due to draghead and propwash (2% of the fines dredged) [kg/s]	38	24
Release rate of sediment to the water column due to overflow (12% of fines entering the hopper) [kg/s]	228	147
Assumed vertical release distribution	Uniform for all plume sources	
Dredging time before overflow [mins]	15	15
Overflow time [mins]	11	42
Speed of dredge during dredging [m/s]	0.7	0.7
Cycle time [h]	2.42	3.37

Table 6-4 Key Assumptions for Plume Release Rates - Backhoe

Dredge Type	Large BHD	
	Channel Widening	Channel Deepening
Production during dredging (m^3/h)	250	210
Dry density (kg/m^3)	2000	2000
Plume source during dredging (kg/s)	3.67	3.08
Operating hours per week	100	70

6.2.4 Meteorological and Hydrodynamic Conditions

In order to assess the impacts of the proposed dredging operations, the most significant dredging operations were simulated for five different months within the 2009-2010 period. These periods include a variety of different wind conditions including strong south-easterlies and some periods of northerlies. The 'long term' wind rose is provided in Figure 6-1 and the wind roses for the assessment months are shown in Figure 6-2.

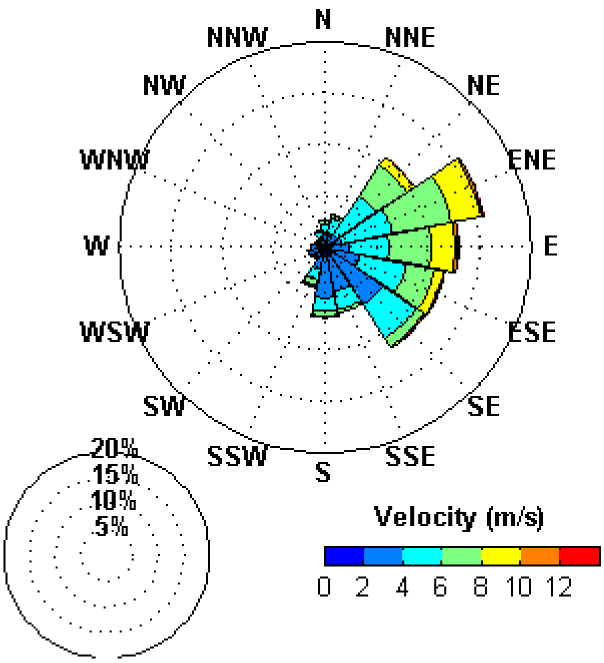


Figure 6-1 Long Term (1995-2011) Wind Rose – Townsville Aero

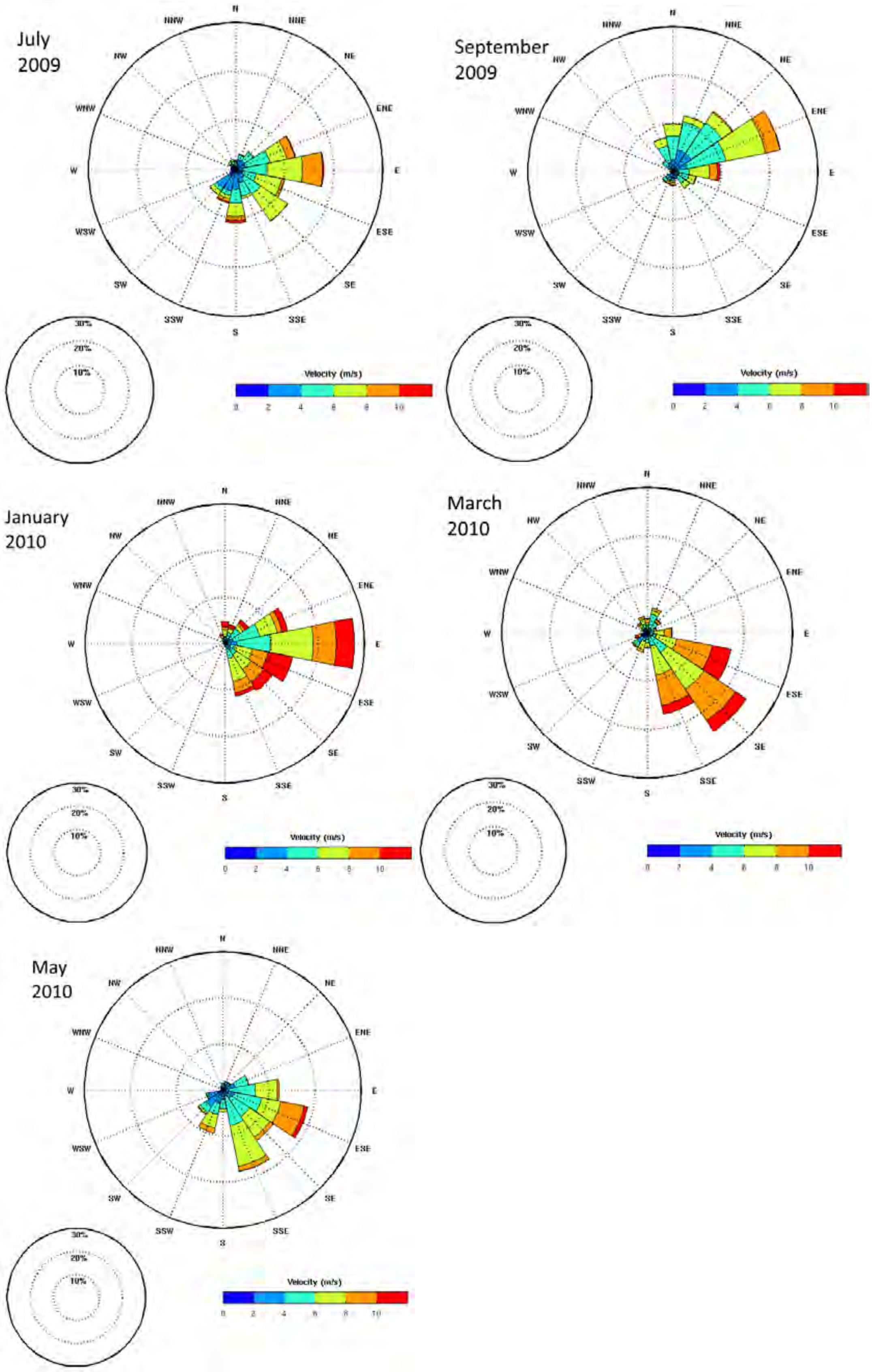


Figure 6-2 Impact Assessment Months – Wind Roses – Townsville Aero

6.2.5 Impact Assessment Methodology

The effects of dredging were assessed based on modelled increases in suspended sediment concentration and sedimentation above natural or ambient levels. Both ambient and dredge related signals have been resolved in the predictive model, which allows for an understanding of how significant the dredge contribution is in relation to ambient conditions.

The water column turbidity impacts associated with dredging-related suspended sediment were derived by converting the modelled Total Suspended Solids (TSS) levels into an equivalent turbidity value using the relationship developed in Section 3.3.3. Depth-averaged turbidity values are presented here since they are most relevant to assessing ecological impacts due to the reduction in seabed Photosynthetically Active Radiation (PAR). Nearbed turbidity is also presented in order to indicate the maximum concentrations within the water column. Sedimentation impacts were derived from the daily rate of change in bed sediment mass associated with the dredge fractions. The adopted sedimentation rate units are $mg/cm^2/day$.

The anticipated effects of dredging have been assessed using two different presentation techniques:

- Time series at sensitive receptor sites; and
- Spatial plots based on percentile analysis.

6.2.5.1 Time Series Analysis

Time series provide a simple way to present turbidity increases due to dredging at predetermined points of interest. Having simulated both dredging and ambient sediment, the time series show both these contributions to the total signal and in doing so provide important information on the relative magnitude of the dredging related signal.

The time series plots of turbidity and sediment deposition for the small TSHD dredging dense clayey sand material during Stage 3 channel deepening are presented in Attachment D (since this activity produced the most significant suspended sediment plumes). The locations used for model time series outputs are shown in Figure 6-3. Results are presented at Sites 4, 5, 6 and 22 are presented for three of the simulated 30-day periods – July 2009, September 2009 and March 2010 – to represent a range of possible seasonal conditions.

6.2.5.2 Percentile Analysis

Each dredging activity was simulated over a 30 day period. Spatial representations of the dredging impacts were based on percentile exceedance analysis of the model results. The 30 day window period is somewhat arbitrary but in a physical hydrodynamic context represents the approximate duration of two (2) consecutive spring-neap tidal cycles, while in an ecological context it is a meaningful timescale for assessing impacts to some key sensitive receptors in the area (e.g. dominant seagrass Halolphila ovalis).

The percentile impact plots correspond to the predicted increase in turbidity/sedimentation statistics over ambient conditions that are attributable to the dredging. It is important to note that the presented turbidity percentile plots do not represent the plume extent at any one particular instant in time.

Percentile values considered in this report are 95th and 50th, which correspond to exceedance durations of 36hrs (5%) and 15 days (50%) respectively for the 30 day simulation. The highest percentiles correspond to relatively acute and short-lived increases in turbidity/sedimentation while the lower percentiles correspond to more chronic longer-term increases.

The spatial percentile exceedance dredging impact plots are presented in tandem with the equivalent modelled ambient percentile statistics, calculated as the average over all five of the 30 day modelling periods. This allows the increases in turbidity/sedimentation due to dredging to be seen relative to the modelled ambient conditions.

Key features of the dredging impact analysis methodology include:

- Consideration of a range of impact durations from acute to chronic.
- Can account for the influence of a variety of meteorological conditions.
- A similar analysis applied to the baseline data can quantify the ambient conditions including natural variability across different periods. This can be used to derive meaningful thresholds for the impacts.

For the most significant dredging activities (i.e. TSHD), the simulation was carried out for an ensemble of five different 30 day periods during different seasons and the results were aggregated to determine the likely range of potential impacts. The 'Expected Case' impacts were determined on the basis of the ensemble average turbidity and deposition percentiles. The 'Worst Case' impacts were determined on the basis of the ensemble maximum turbidity and deposition percentiles.

Twelve months of baseline turbidity monitoring was undertaken as part of the project which has allowed for the derivation of contour limits for the presentation of the percentile impact plots that are meaningful at specific sites. It should be noted that different thresholds (and therefore different contour limits) are appropriate for the different percentiles.

Figure 6-3 Sites for Time Series Outputs

6.3 'Expected Case' Dredging Impacts

6.3.1 PEP Stage 1

The PEP Stage 1 consists of three main dredging operations.

- The removal of soft sediments under retaining wall structures along the perimeter of the proposed interim reclamation area. This will be carried out by backhoe.
- Widening the Platypus Channel on its western side (a new width of 180m at the Outer Harbour, tapering to 135m at its northern end), and widening the Sea Channel on its eastern side (for 135m at the southern end to 120m at its northern end). The soft marine sediments and dense clayey sands will be dredged by TSHD (20% of the total volume). The stiff, very stiff and hard clays will be dredged by backhoe (80% of the total volume).
- The dredging of Berth 12 to an elevation of -13.5mLAT by backhoe.

The geometry assumed for the channel dredging simulations in this stage corresponds to the existing bed elevations for the channel and adjacent areas, with the interim reclamation in place. The plume sources for the channel widening are released into model cells adjacent to the existing channel. The plumes generated during Berth 12 dredging were not modelled because they would have a smaller influence than the plumes generated during the removal of soft surface sediments under reclamation wall structures.

6.3.1.1 Removal of soft sediments under reclamation wall structures

This initial dredging activity involves the removal of soft surface sediments along the footprint of the proposed reclamation bunds using a backhoe dredge. The modelled impact of the dredging operation is shown in Figure 6-4 to Figure 6-8. The 30 day modelling period shows the dredge working in a single location. The extent of the influence of the suspended sediment plumes will be similar for other locations along the perimeter of the reclamation bunds. The influence of suspended sediment plumes and deposited sediment is restricted to the immediate vicinity of the dredging operation.

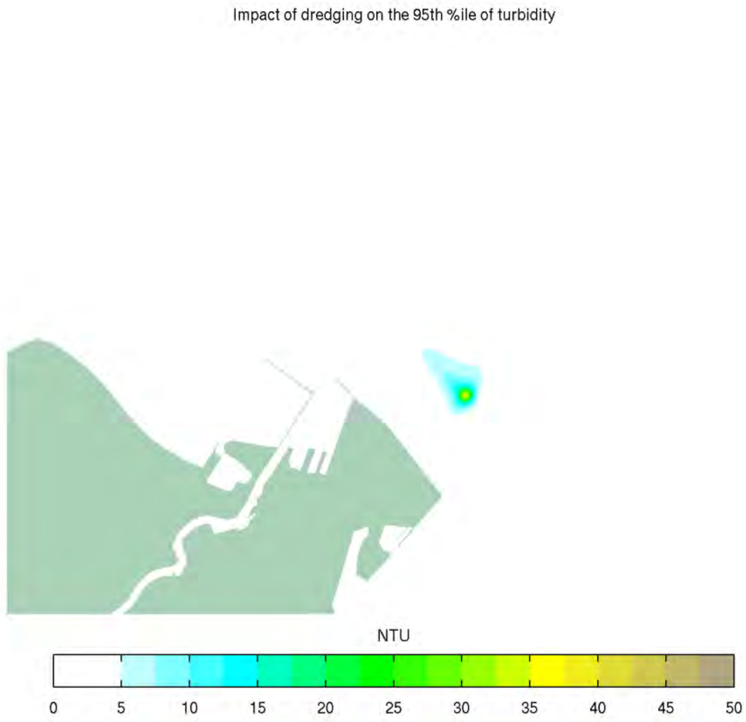


Figure 6-4 Stage 1 – Soft Sediments – 95th Percentile Depth Average Turbidity: Impact of Dredging

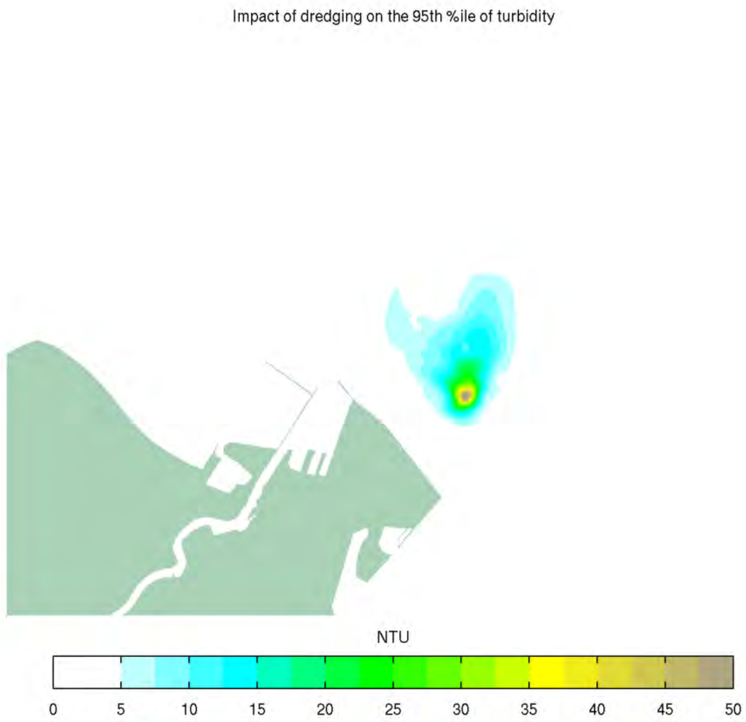


Figure 6-5 Stage 1 – Soft Sediments – 95th Percentile Bottom 1m Turbidity: Impact of Dredging

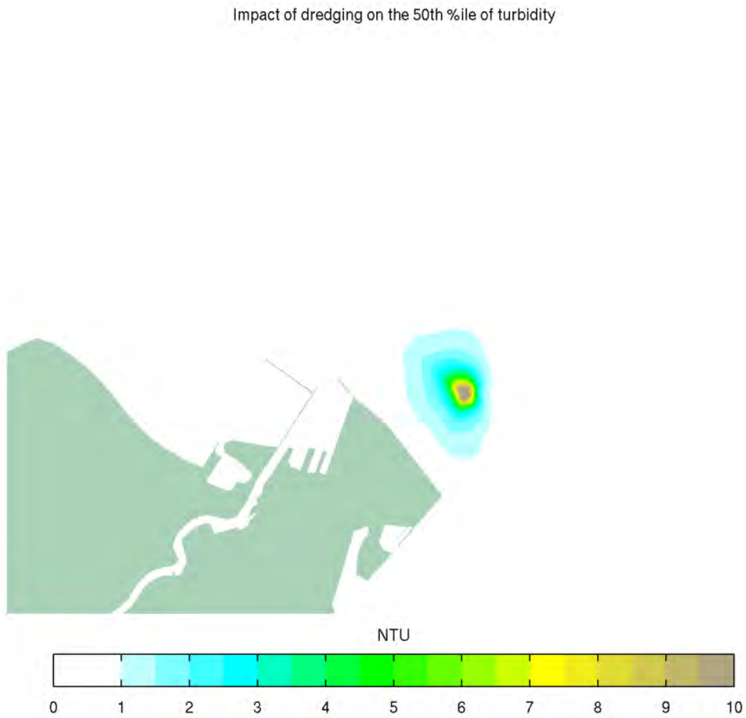


Figure 6-6 Stage 1 – Soft Sediments – 50th Percentile Depth Average Turbidity: Impact of Dredging

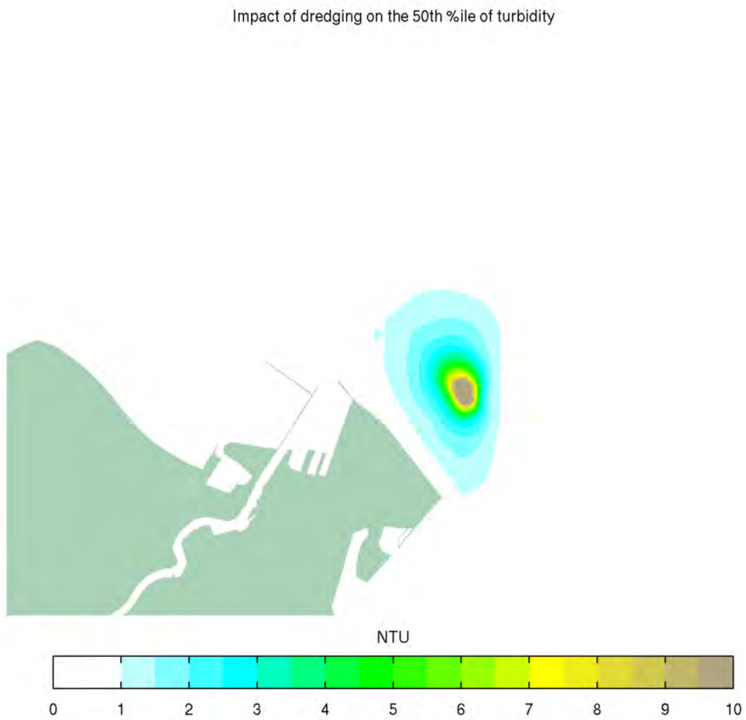
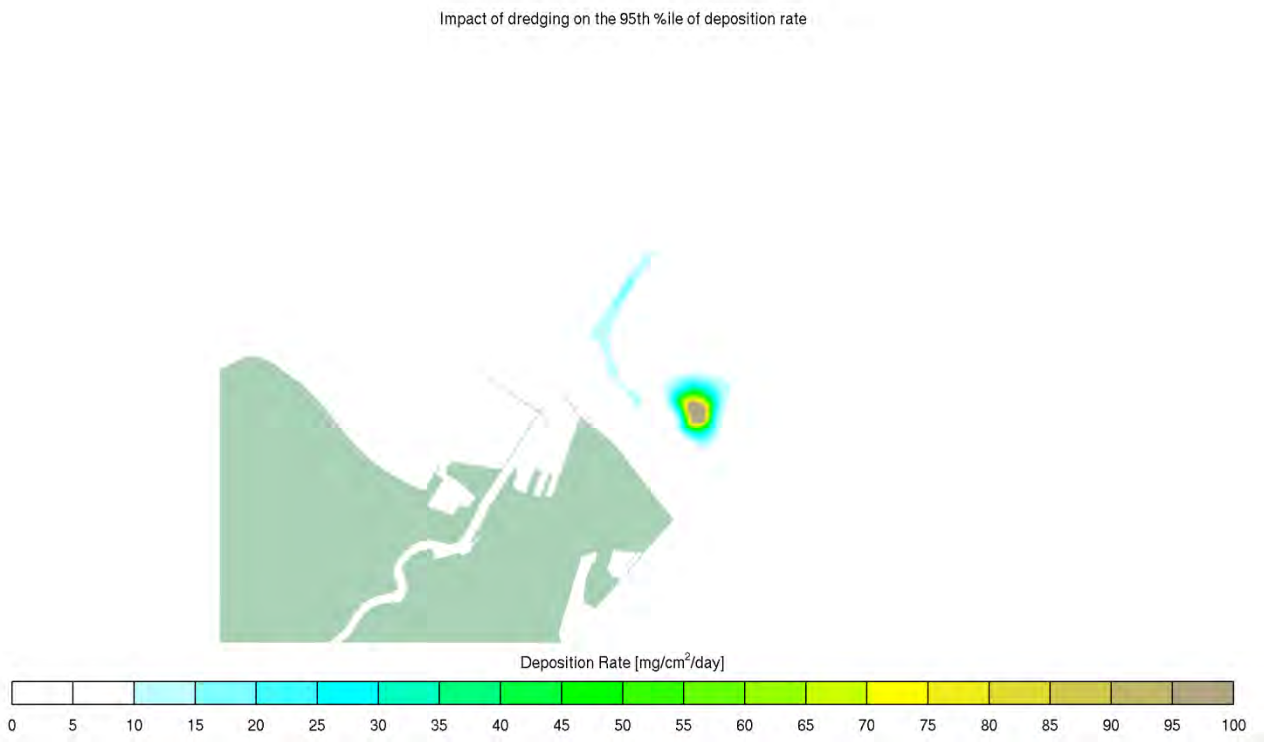


Figure 6-7 Stage 1 – Soft Sediments – 50th Percentile Bottom 1m Turbidity: Impact of Dredging



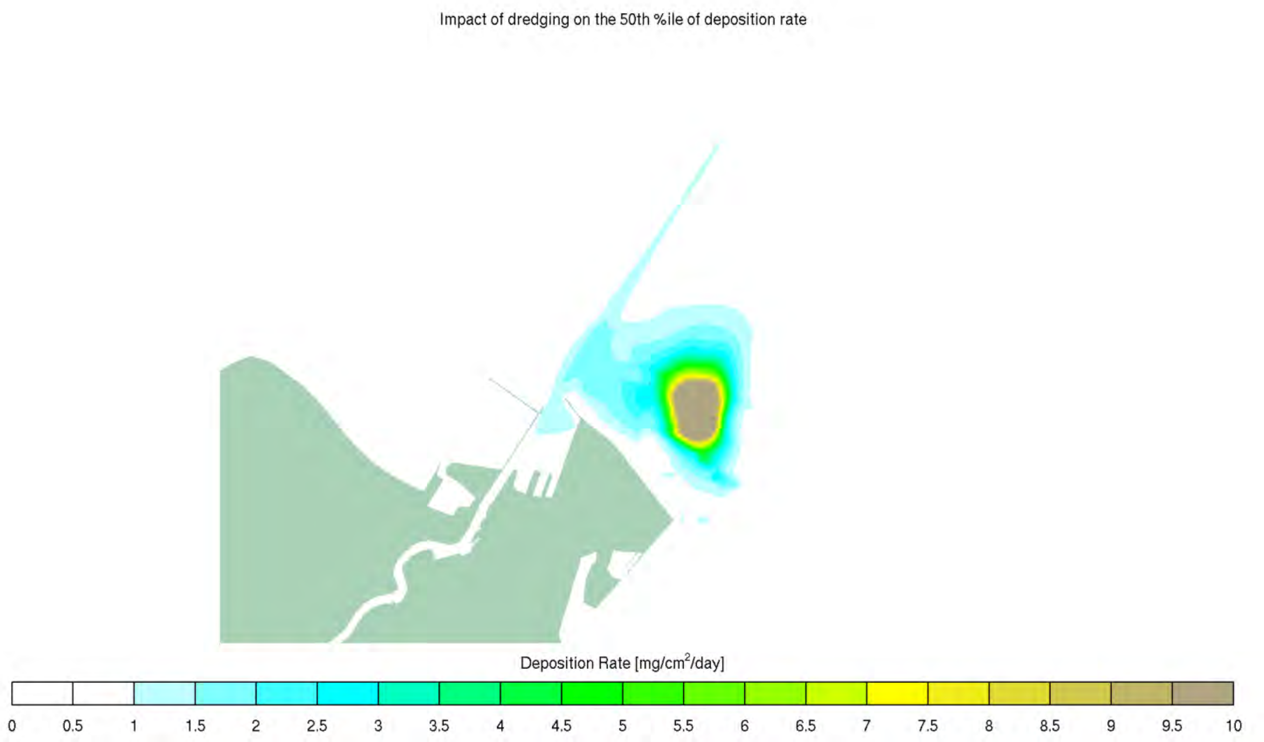


Figure 6-8 Stage 1 – Soft Sediments – Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

6.3.1.2 Widening of Platypus and Sea Channels by Small TSHD

The modelled impact of dredging during the widening of the Platypus and Sea Channels by a small TSHD is shown in Figure 6-9 to Figure 6-14. The impacts shown are representative of the TSHD working in dense clayey sand material (since this generates more extensive plumes than working in soft material). The total campaign duration for the TSHD for this stage of the programme is 16.5 weeks, approximately one third of which will involve working in dense clayey sands.

Figure 6-9 shows the change in the 95th percentile depth-averaged turbidity due to dredging, averaged over the five different 30-day periods that were modelled. Figure 6-10 shows the change in the 95th percentile turbidity in the bottom 1m layer of the model due to dredging (again, averaged over the five 30-day periods that were modelled). These figures indicate the likely acute (short term) influence of suspended sediment plumes generated by the TSHD.

Figure 6-11 shows the change in the 50th percentile depth-averaged turbidity due to dredging and Figure 6-12 shows the change in the 50th percentile turbidity in the bottom 1m layer of the model due to dredging. These figures indicate the likely chronic (persistent) influence of suspended sediment plumes generated by the TSHD.

Figure 6-13 shows the change in the 95th and 50th percentile deposition rate due to dredging, while Figure 6-14 shows the total amount of dredged material deposited in a 30 day simulation (the average of the five months that were modelled). Overall, the modelled turbidity and deposition impacts are limited to the immediate vicinity of the channel.

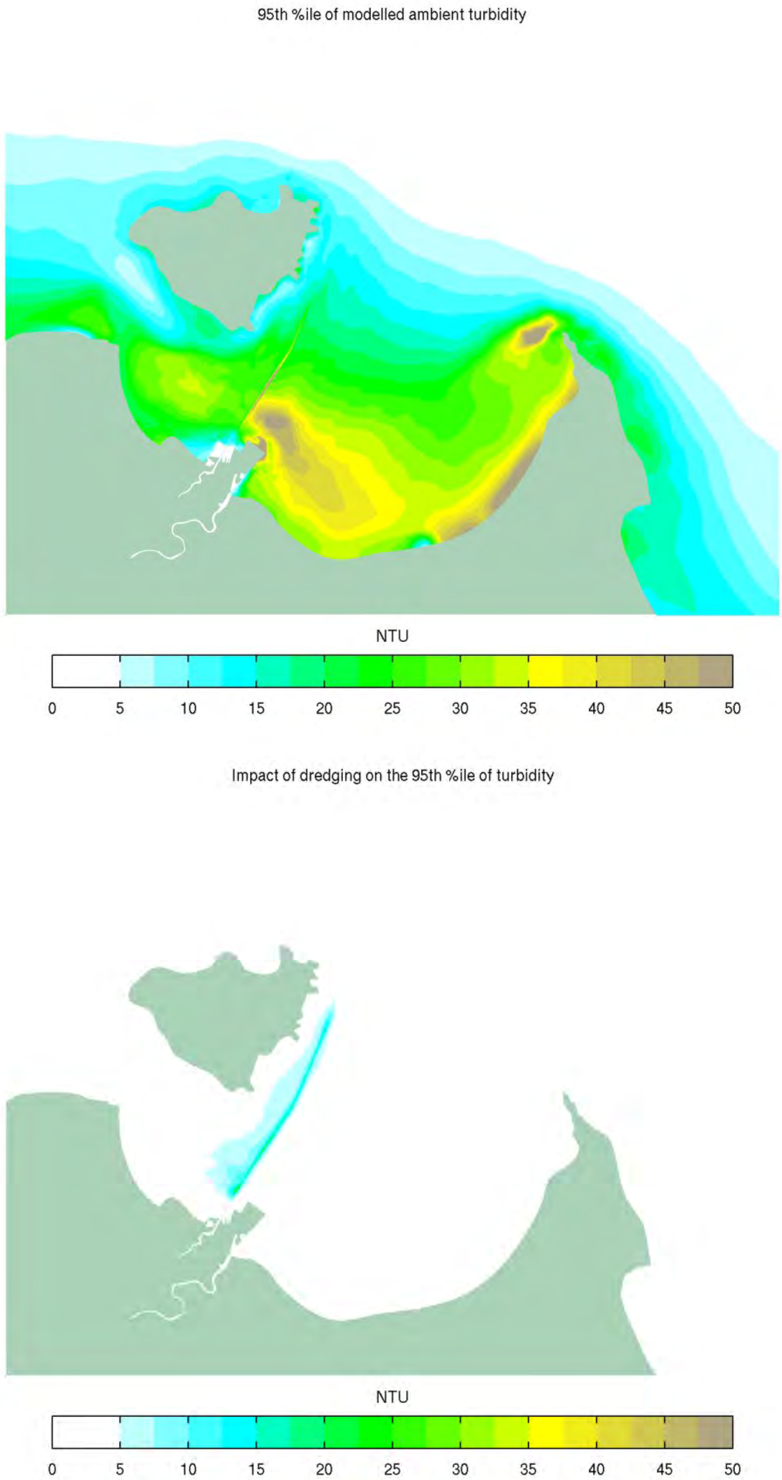
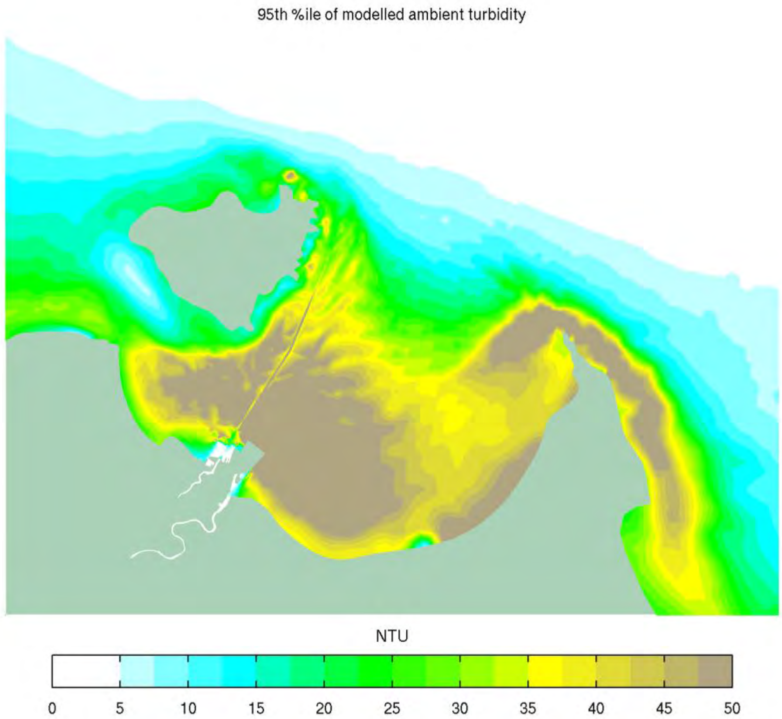


Figure 6-9 Widening of Platypus and Sea Channels by Small TSHD - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



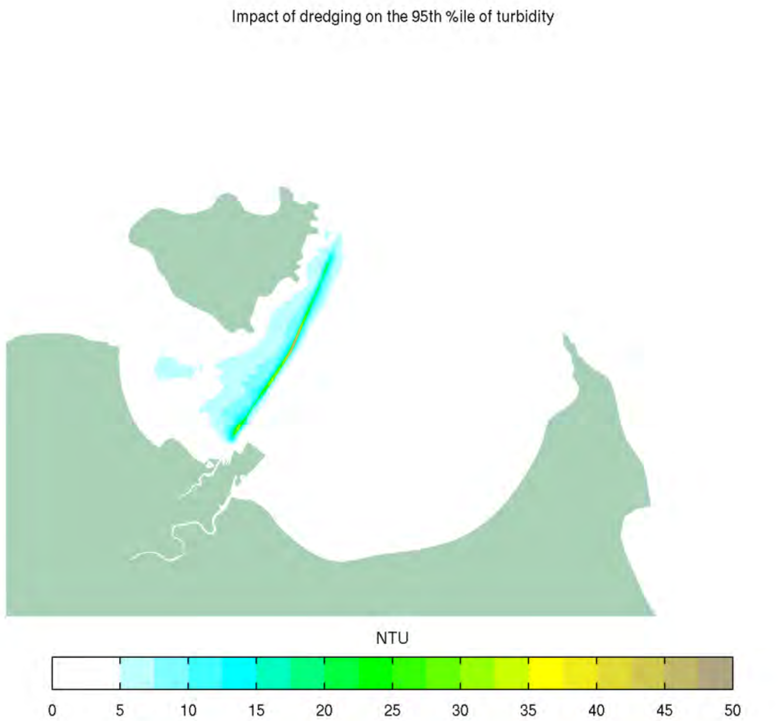


Figure 6-10 Widening of Platypus and Sea Channels by Small TSHD - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

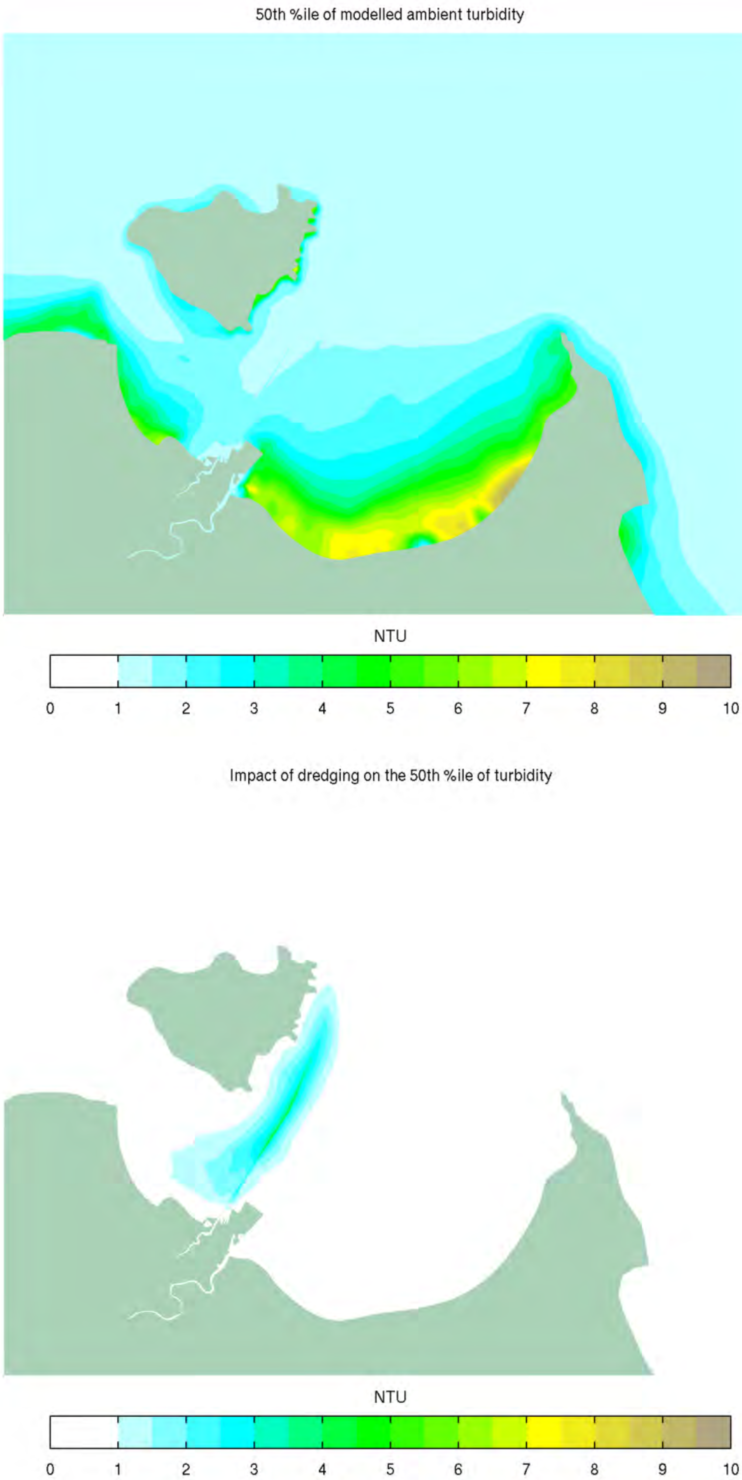


Figure 6-11 Widening of Platypus and Sea Channels by Small TSHD - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

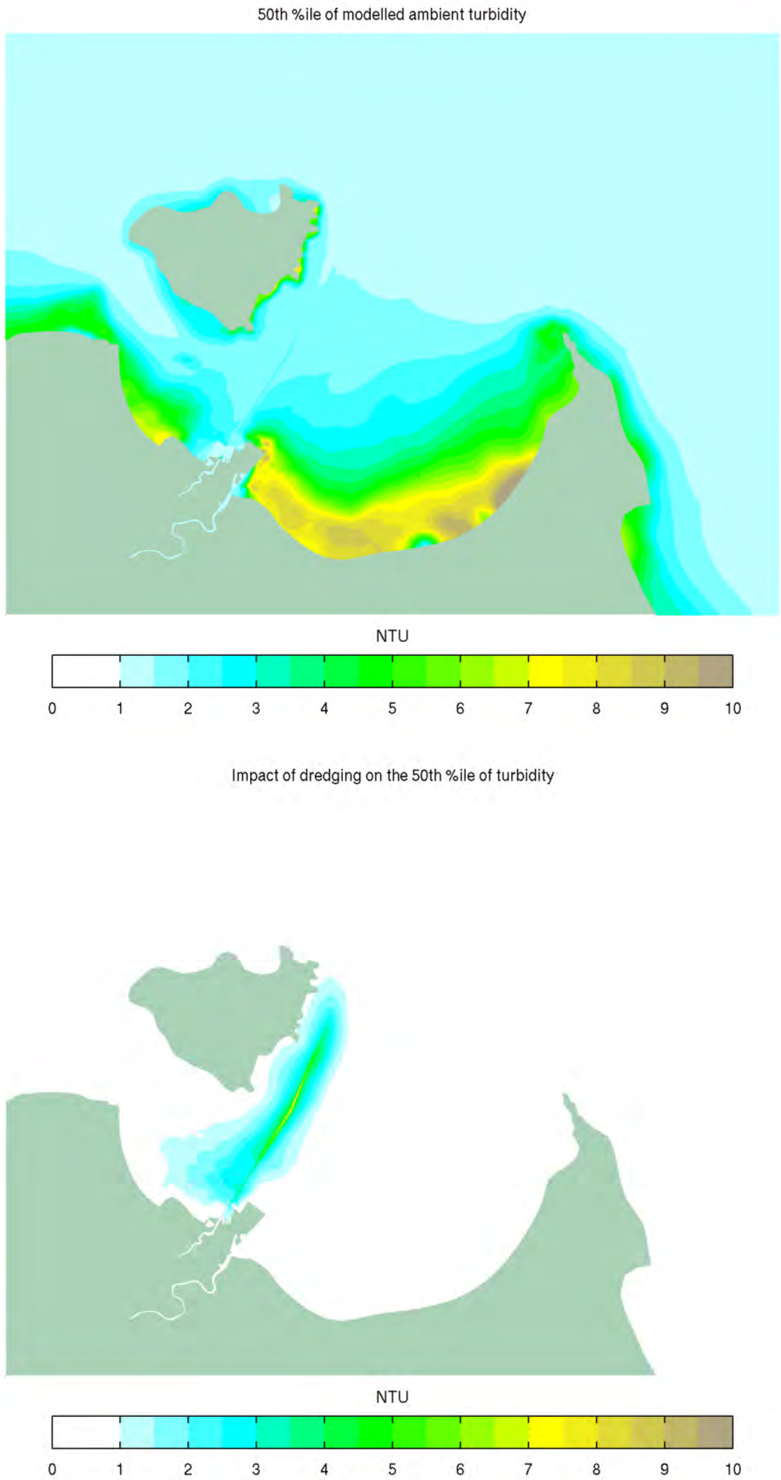


Figure 6-12 Widening of Platypus and Sea Channels by Small TSHD - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

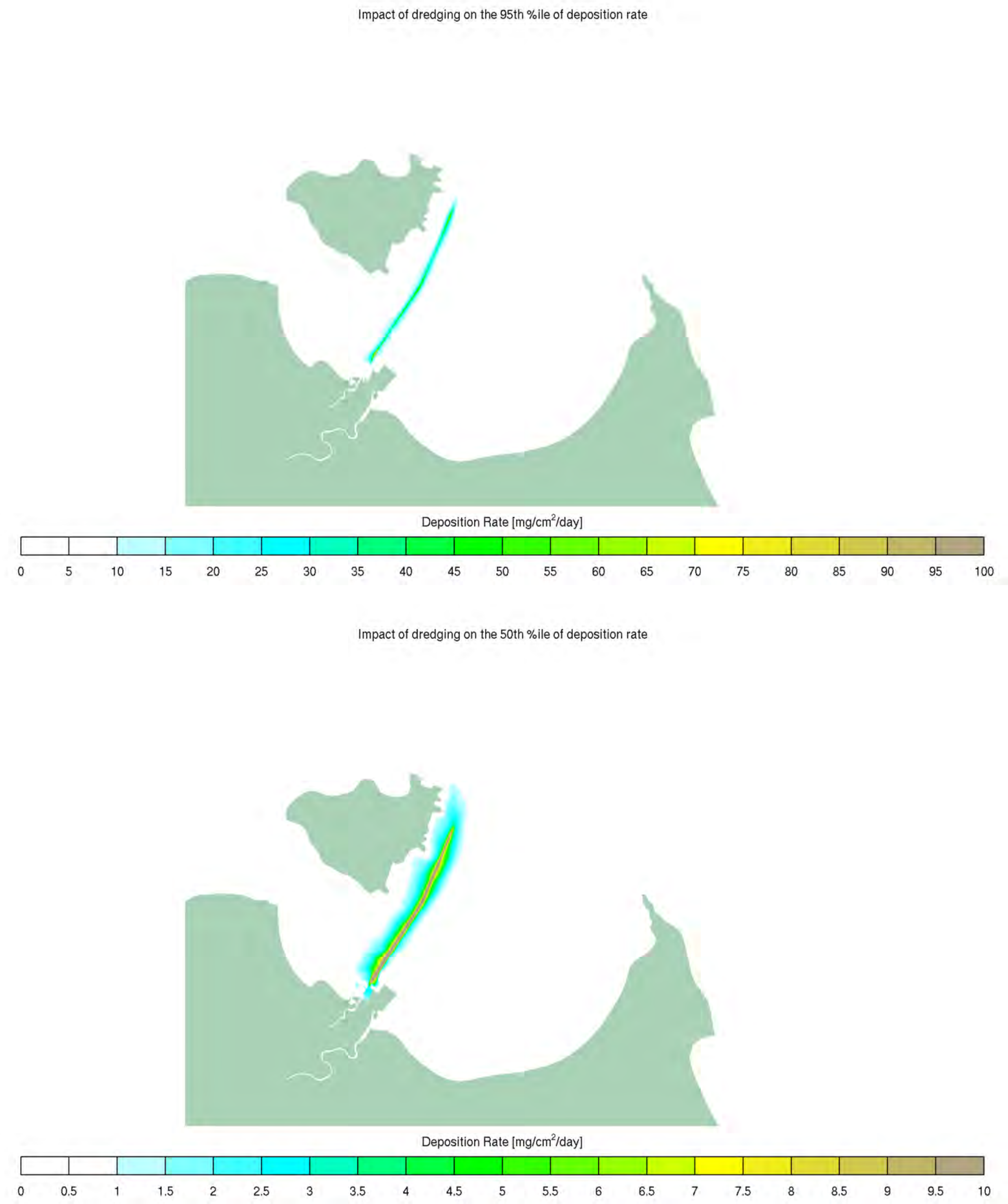


Figure 6-13 Widening of Platypus and Sea Channels by Small TSHD - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

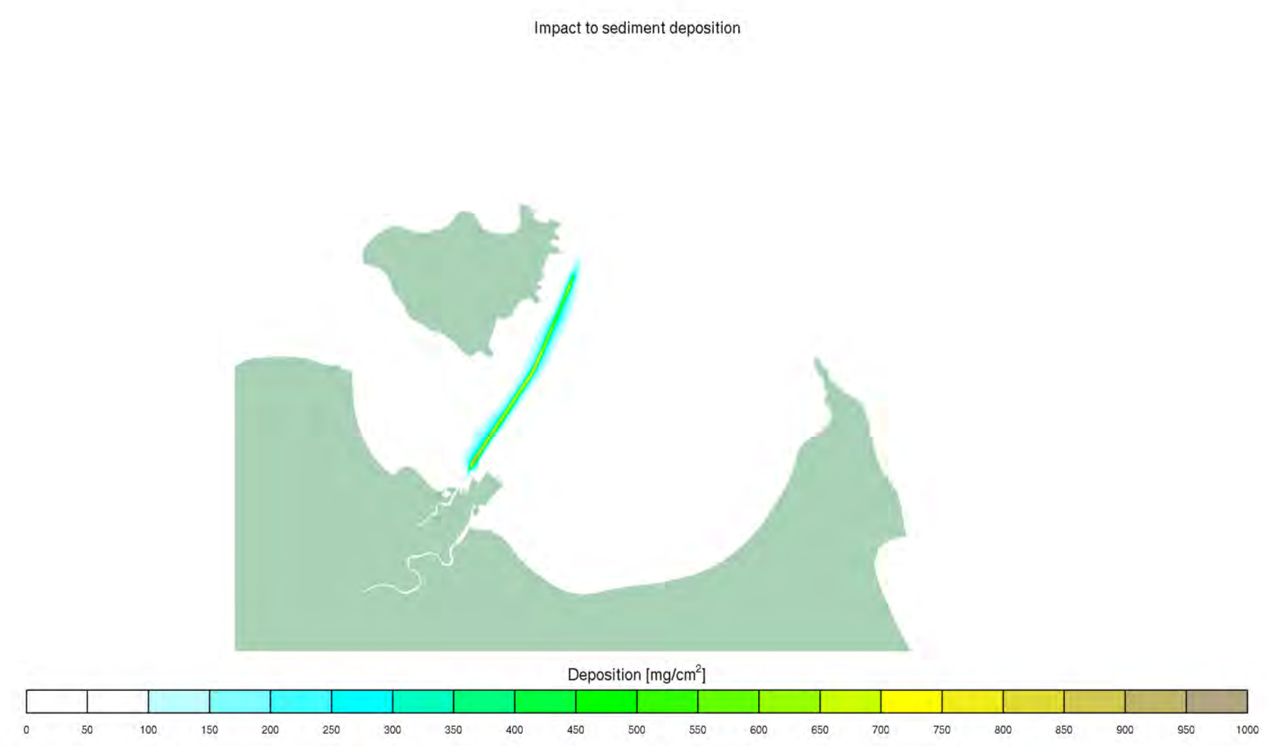


Figure 6-14 Widening of Platypus and Sea Channels by Small TSHD - Deposition of Dredged Sediment After 30 Days

6.3.1.3 Widening of Platypus and Sea Channels by Backhoe

The modelled impact of dredging during the widening of the Platypus and Sea Channels by a backhoe is shown in Figure 6-15 to Figure 6-20. Note that the impact plots presented here show the superposition (addition) of the impacts of a backhoe dredge working at five different locations along the shipping channel. The impacts shown are representative of a typical 30 day period of backhoe dredging at each location. The influence of dredging plumes generated by the backhoe at intermediate locations along the channel can be estimated by interpreting the plots. It can be seen that the acute and chronic impacts of the backhoe dredging operation are restricted to the immediate vicinity of the dredging location. The backhoe dredging campaign for this stage of the project is expected to take approximately two years.

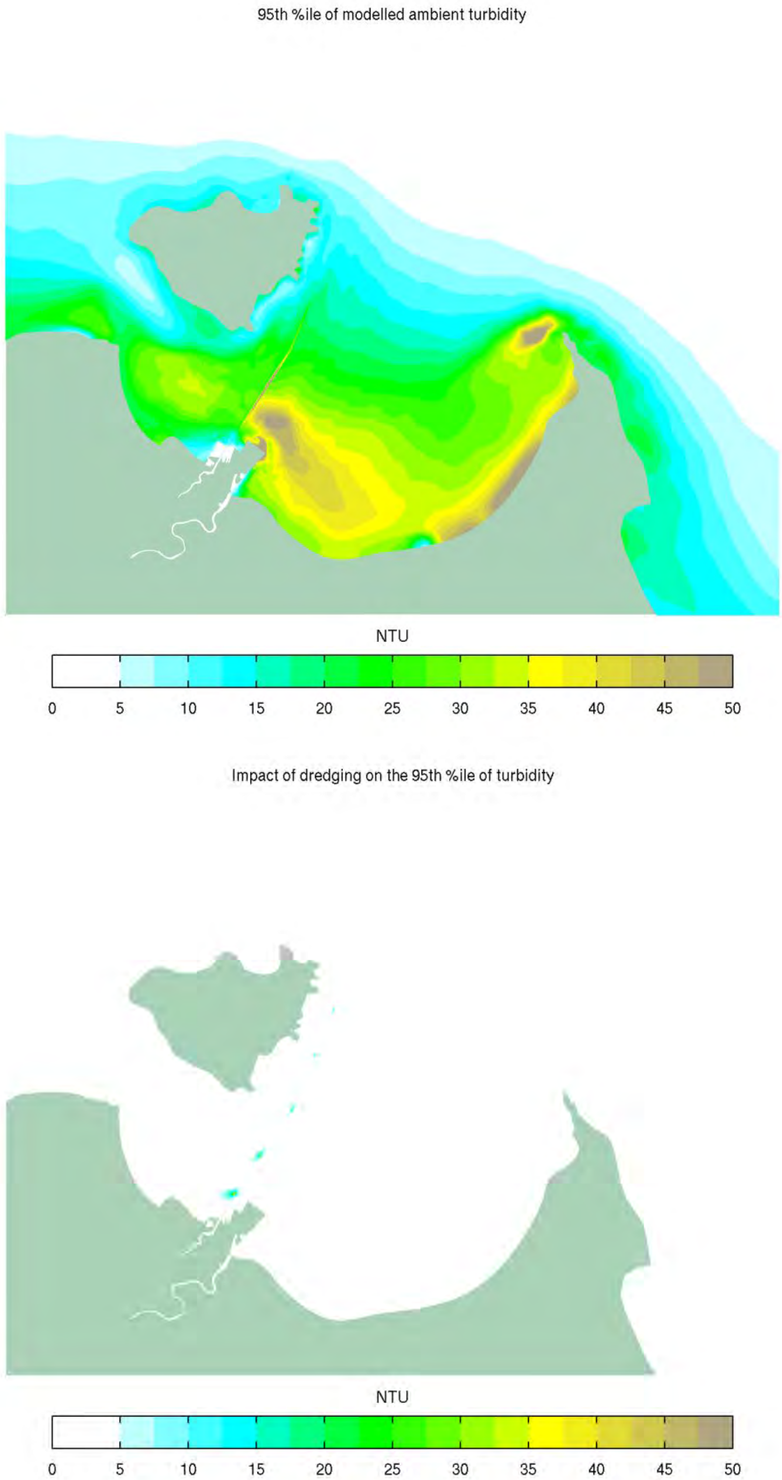


Figure 6-15 Widening of Platypus and Sea Channels by Backhoe - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

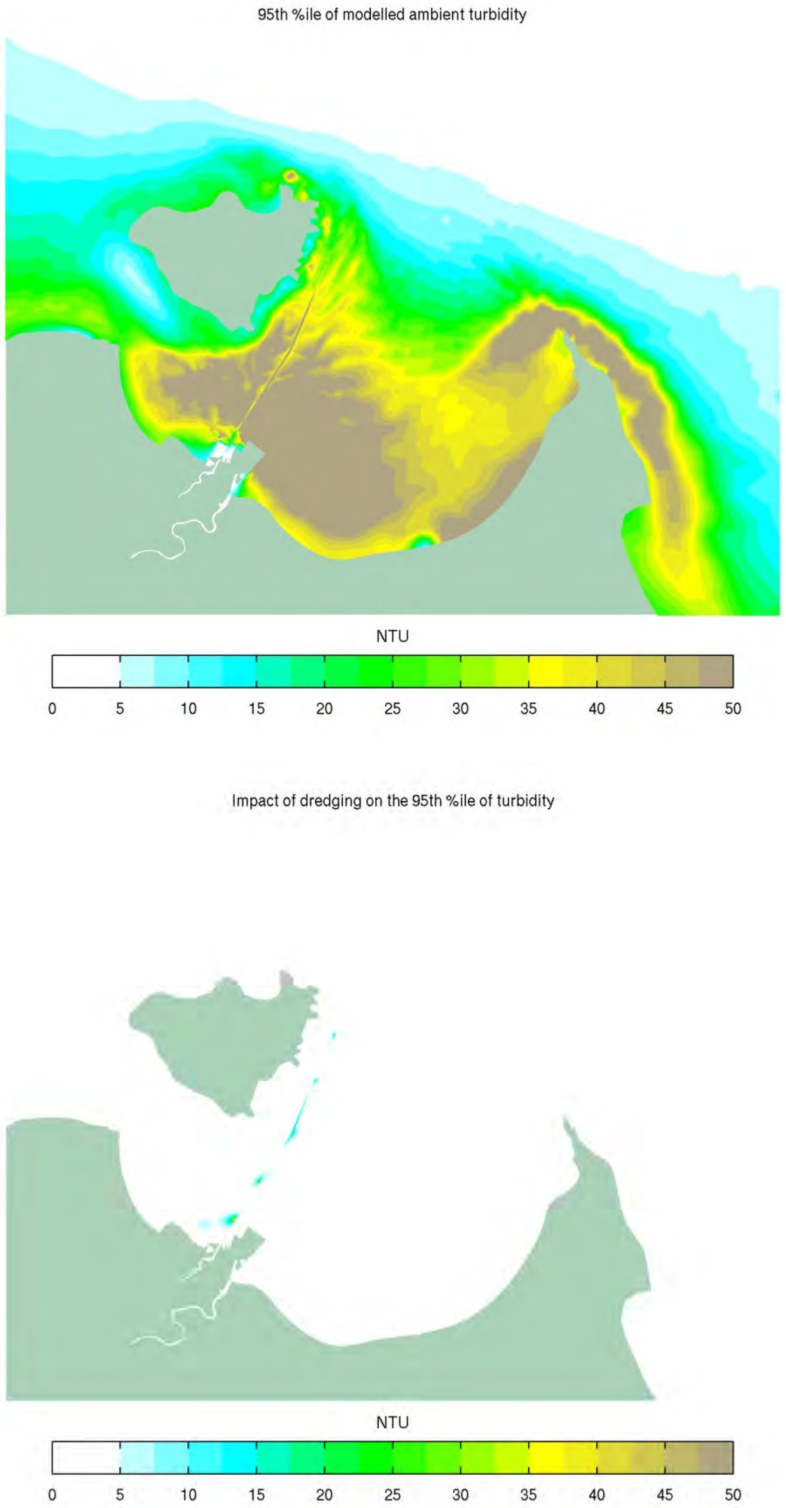


Figure 6-16 Widening of Platypus and Sea Channels by Backhoe - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

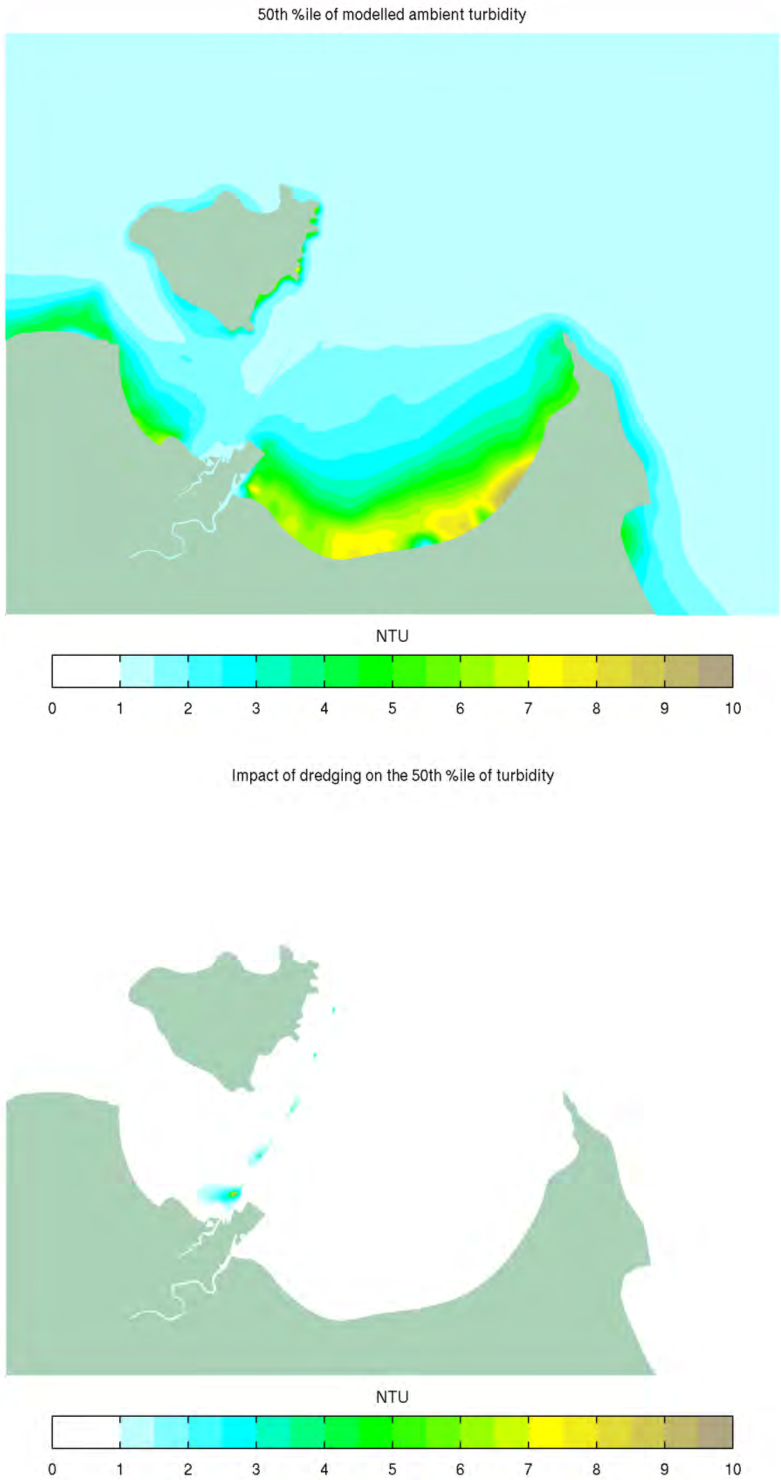


Figure 6-17 Widening of Platypus and Sea Channels by Backhoe - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

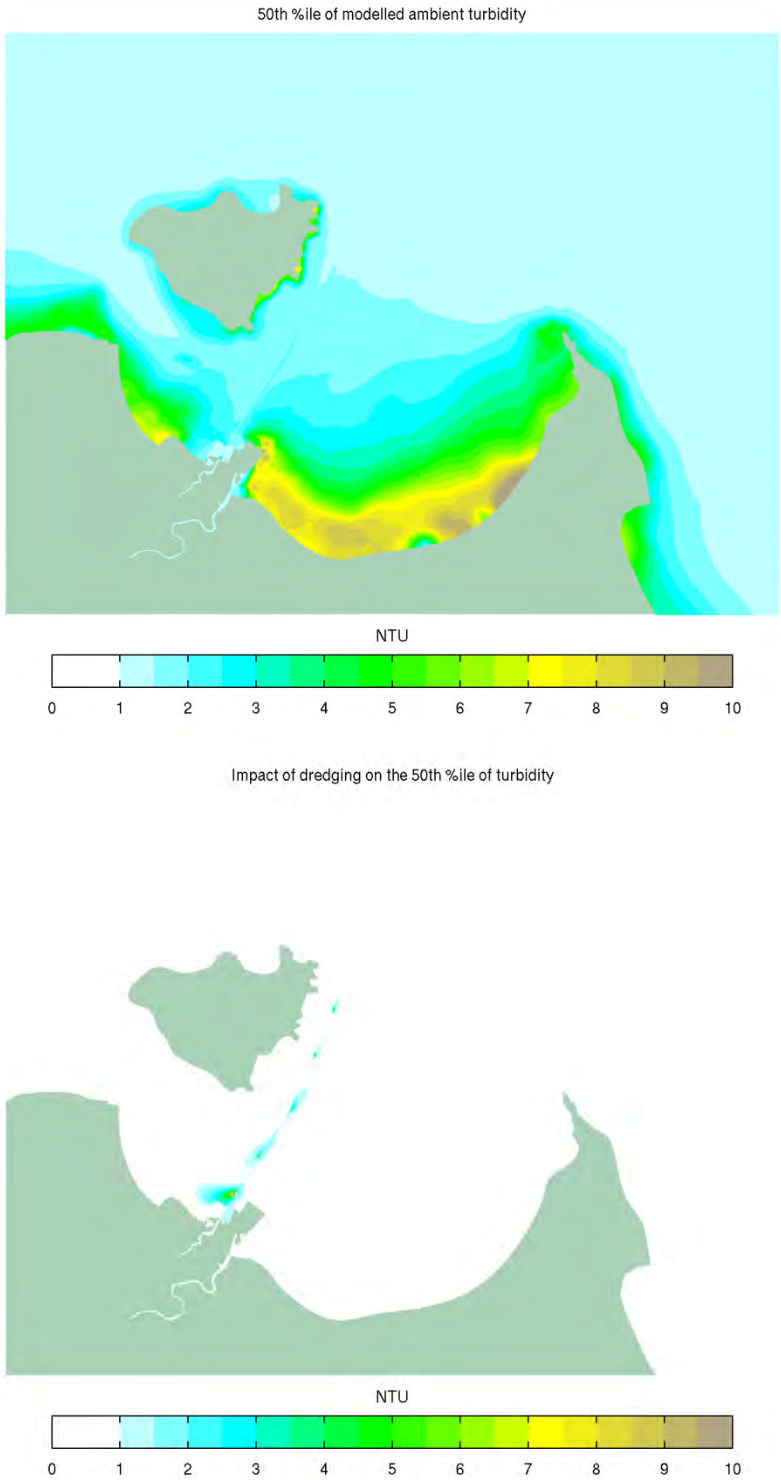
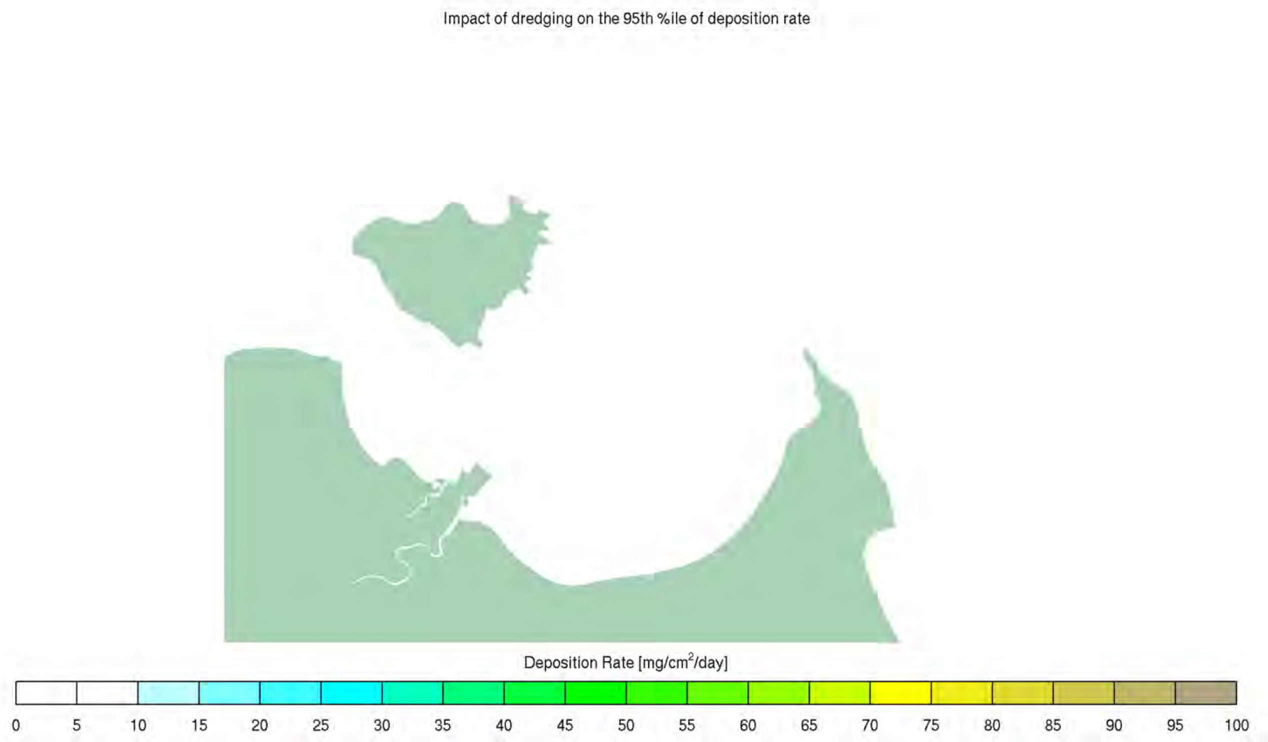


Figure 6-18 Widening of Platypus and Sea Channels by Backhoe - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



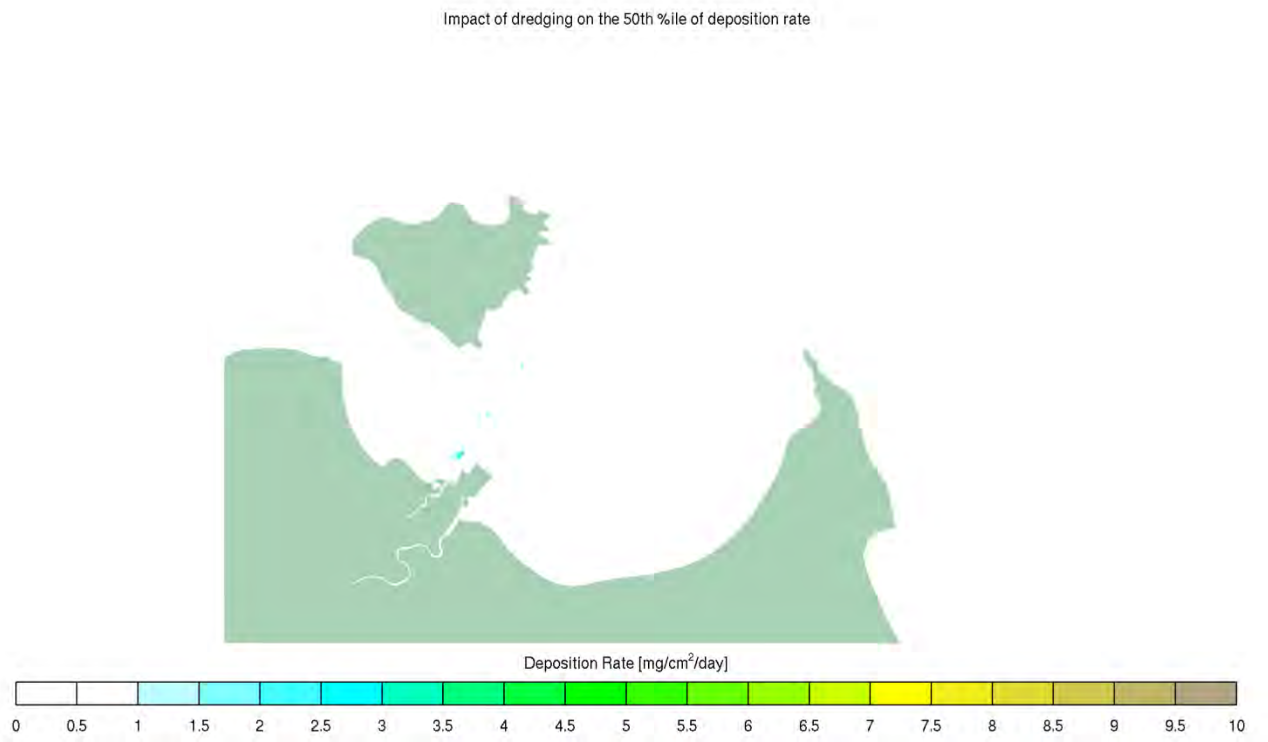


Figure 6-19 Widening of Platypus and Sea Channels by Backhoe - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

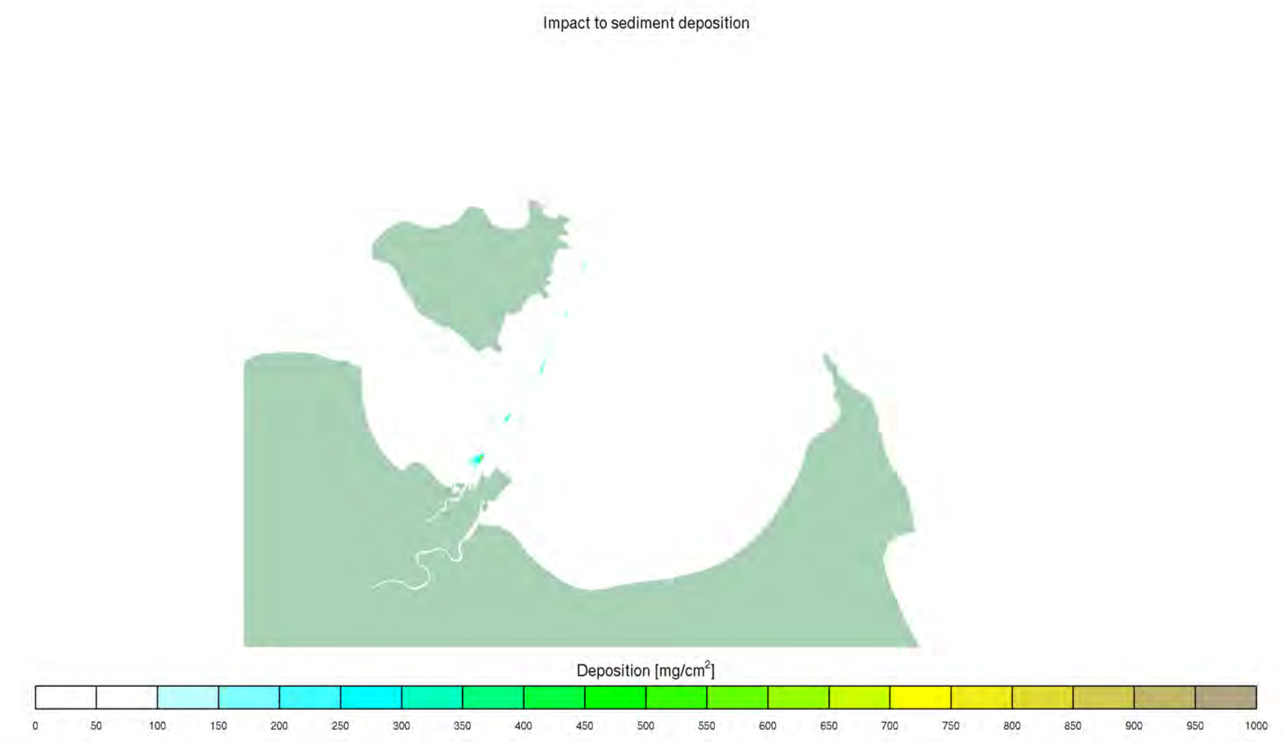


Figure 6-20 Widening of Platypus and Sea Channels by Backhoe - Final Deposition of Dredged Sediment After 30 Days (Five Locations)

6.3.2 PEP Stage 2

The PEP Stage 2 involves dredging berths 14, 15 and 16 in the Outer Harbour, as well as soft sediments under the footprint of the final reclamation bunds and breakwater. This will be carried out by backhoe dredging.

The impacts of Stage 2 dredging are shown in Figure 6-21 to Figure 6-25. The model was run for five different backhoe locations within the berthing areas, and the highest impacts for any of the five simulations are shown for each location in the model domain. Turbidity and deposition impacts are confined to the immediate vicinity of the dredging operation.

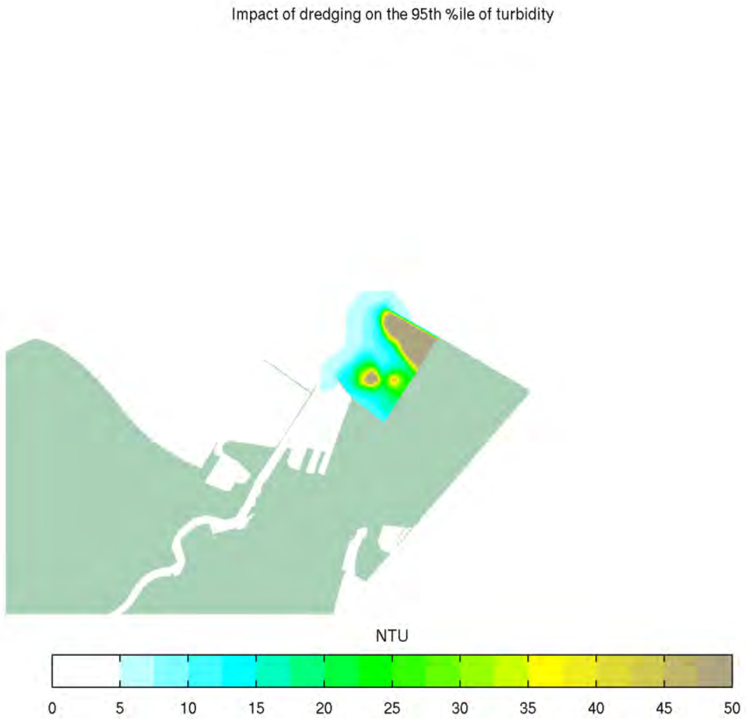


Figure 6-21 Stage 2 – Berths 14, 15 and 16 – 95th Percentile Depth Average Turbidity: Impact of Dredging

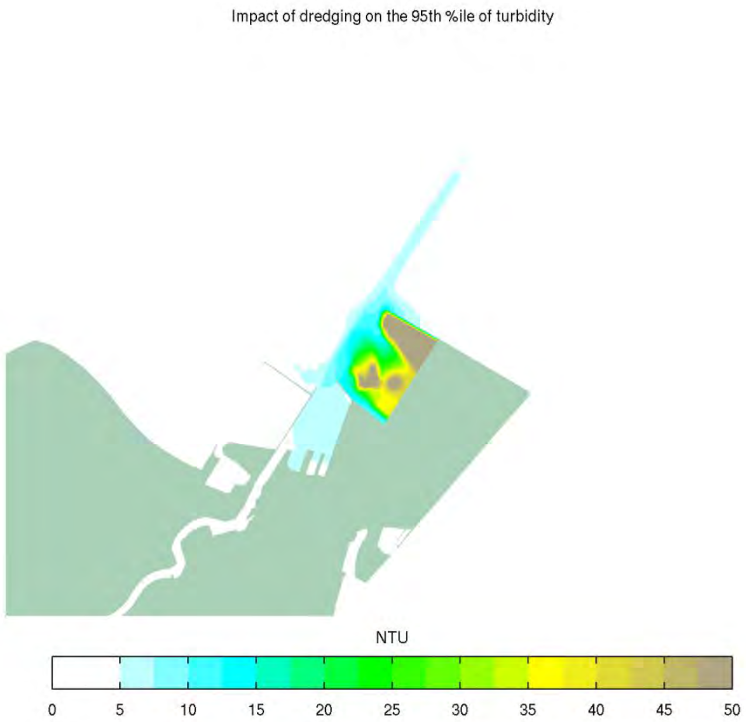


Figure 6-22 Stage 2 – Berths 14, 15 and 16 – 95th Percentile Bottom 1m Turbidity: Impact of Dredging

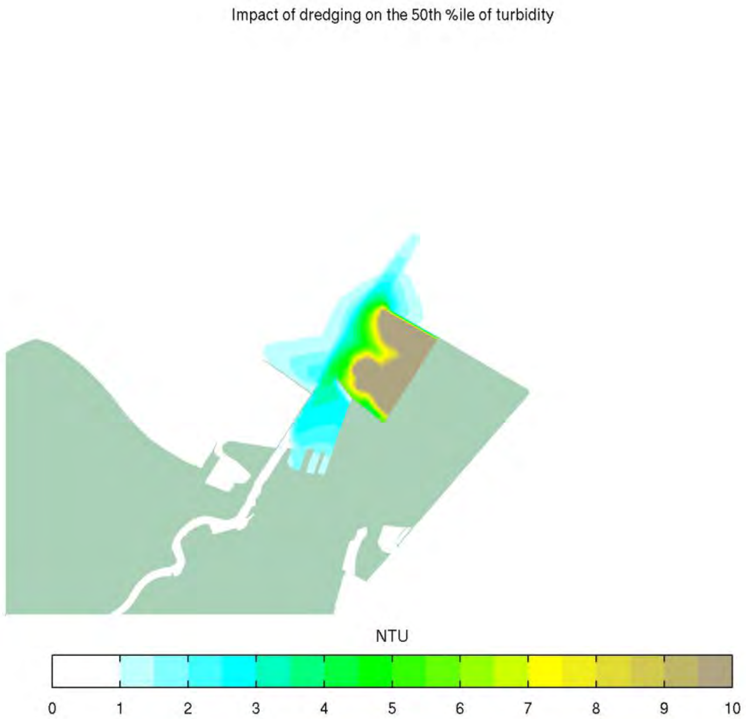


Figure 6-23 Stage 2 – Berths 14, 15 and 16 – 50th Percentile Depth Average Turbidity: Impact of Dredging

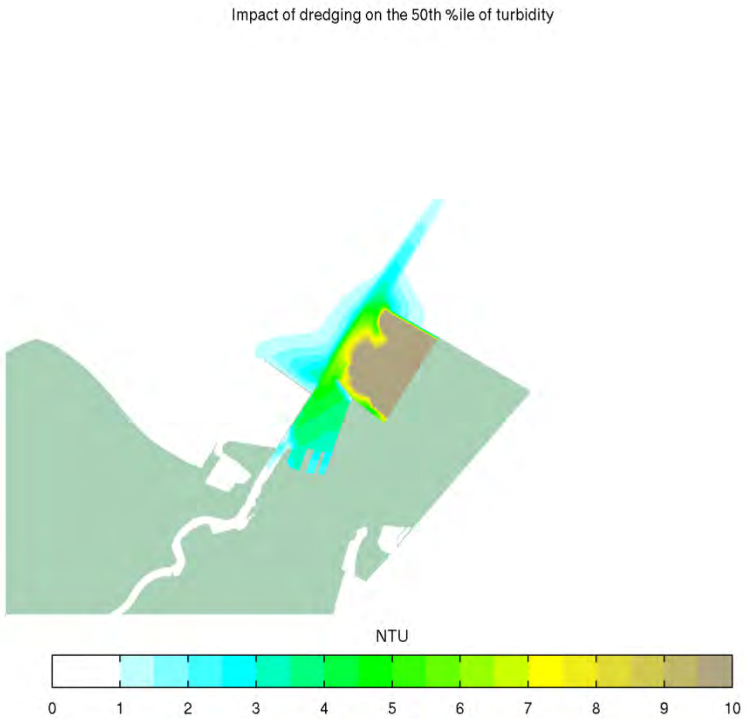


Figure 6-24 Stage 2 – Berths 14, 15 and 16 – 50th Percentile Bottom 1m Turbidity: Impact of Dredging

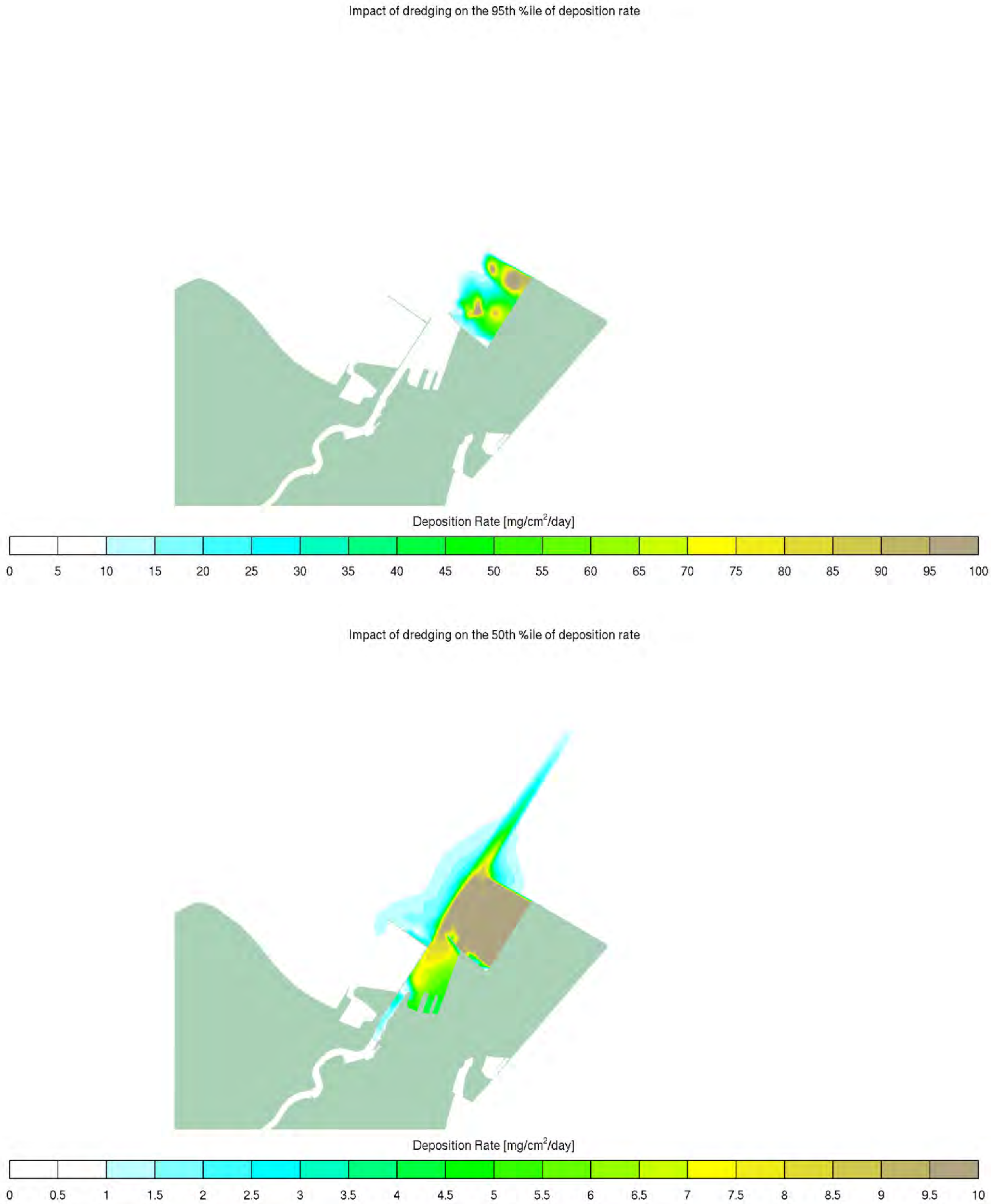


Figure 6-25 Stage 2 – Berths 14, 15 and 16 - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

6.3.3 PEP Stage 3

The PEP Stage 3 consists of two main dredging operations.

- Deepening of the Platypus Channel and the Sea Channel to a bed elevation of -13.5 mLAT (-15.4 mAHD) inclusive of overdredging allowance. The soft marine sediments and dense clayey sands will be dredged by TSHD (20% of the total volume). The stiff, very stiff and hard clays will be dredged by backhoe (80% of the total volume).
- The dredging of the berth pockets for Berths 17 and 18 by backhoe. The impacts for this activity are similar to those of Stage 2 dredging.

The geometry assumed for the channel dredging simulations in this stage corresponds to the post-widening bed elevations for the channel, with the ultimate reclamation in place.

6.3.3.1 Deepening of Platypus Channel and Sea Channel by Small TSHD

The modelled impact of dredging during the deepening of the Platypus Channel by a small TSHD is shown in Figure 6-26 to Figure 6-31. The impacts shown are representative of the TSHD working in dense clayey sand material (since this generates more extensive plumes than working in soft material). The total campaign duration for the TSHD for this stage of the programme is 8 weeks, approximately one third of which will involve working in dense clayey sands.

Figure 6-26 shows the change in the 95th percentile depth-averaged turbidity due to dredging, averaged over the five different 30-day periods that were modelled. Figure 6-27 shows the change in the 95^{th} percentile turbidity in the bottom 1m layer of the model due to dredging (again, averaged over the five 30-day periods that were modelled). These figures indicate the likely acute (short term) influence of suspended sediment plumes generated by the TSHD.

Figure 6-28 shows the change in the 50^{th} percentile depth-averaged turbidity due to dredging and Figure 6-29 shows the change in the 50^{th} percentile turbidity in the bottom 1m layer of the model due to dredging. These figures indicate the likely chronic (persistent) influence of suspended sediment plumes generated by the TSHD.

Figure 6-30 shows the change in the 95^{th} and 50^{th} percentile deposition rate due to dredging, while Figure 6-31 shows the total amount of dredged material deposited in a 30 day simulation (the average of the five months that were modelled). Overall, the modelled turbidity and deposition impacts are limited to the immediate vicinity of the channel.

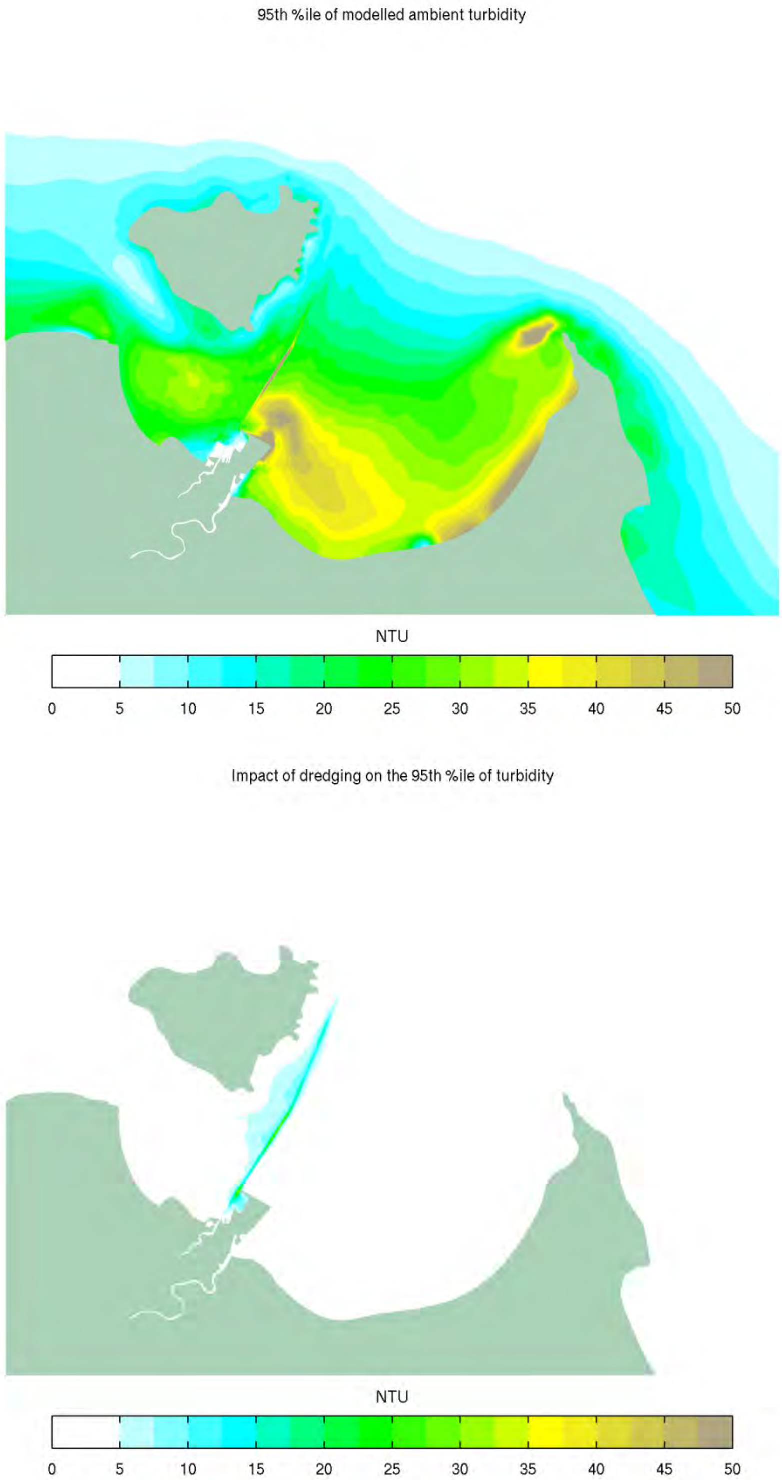
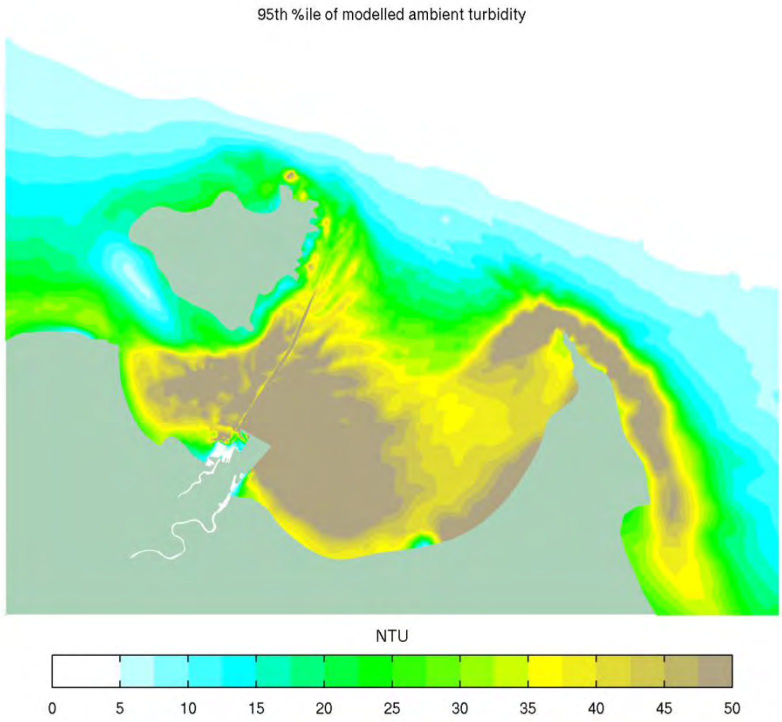


Figure 6-26 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



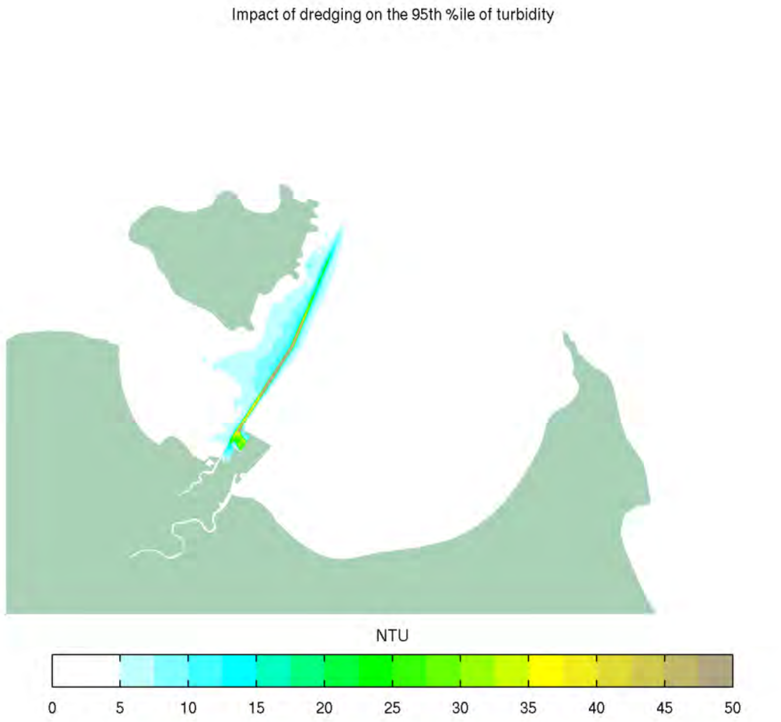


Figure 6-27 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

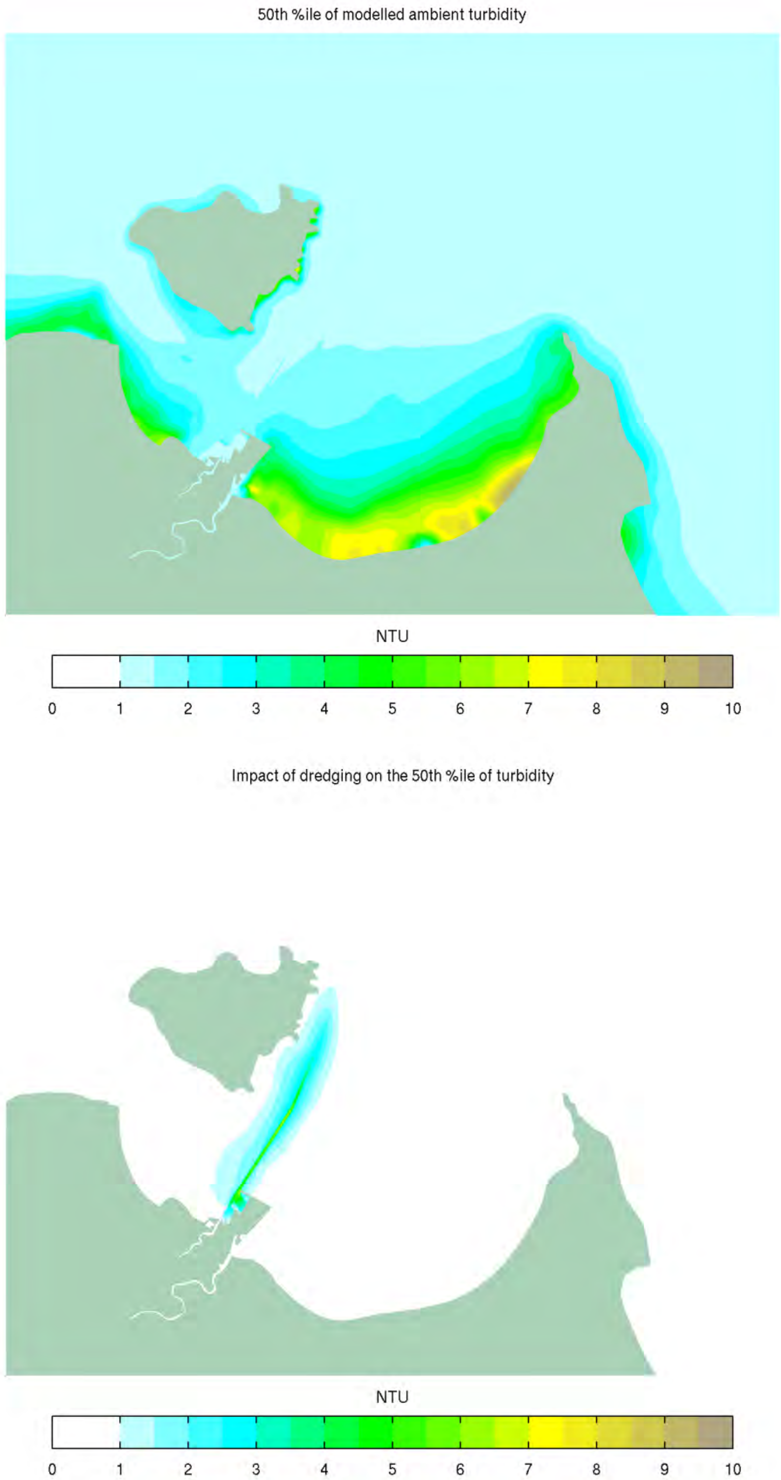
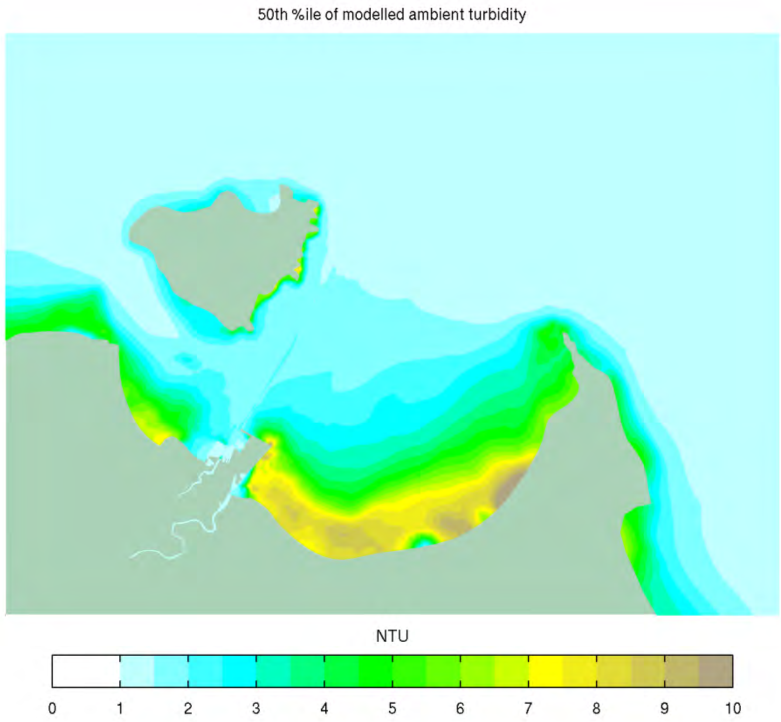


Figure 6-28 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



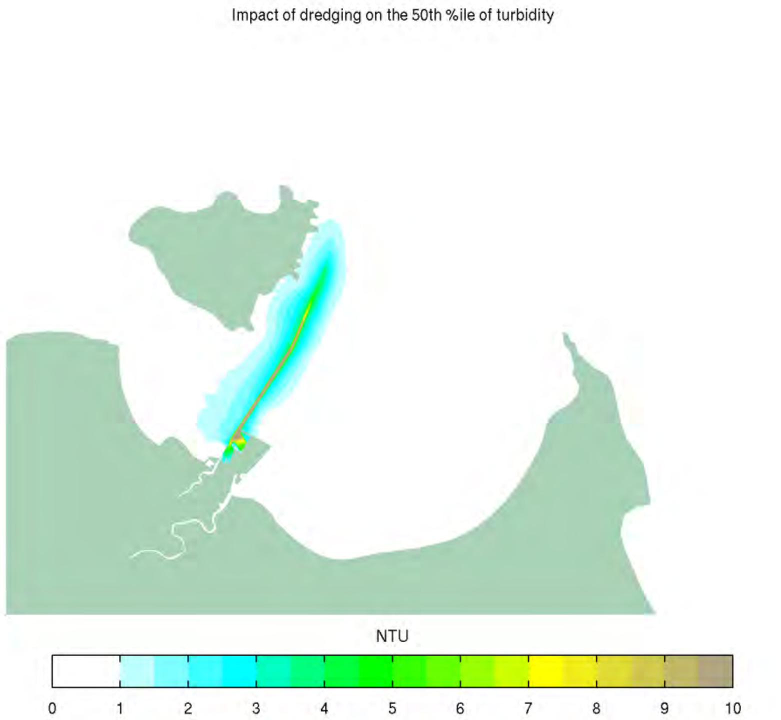
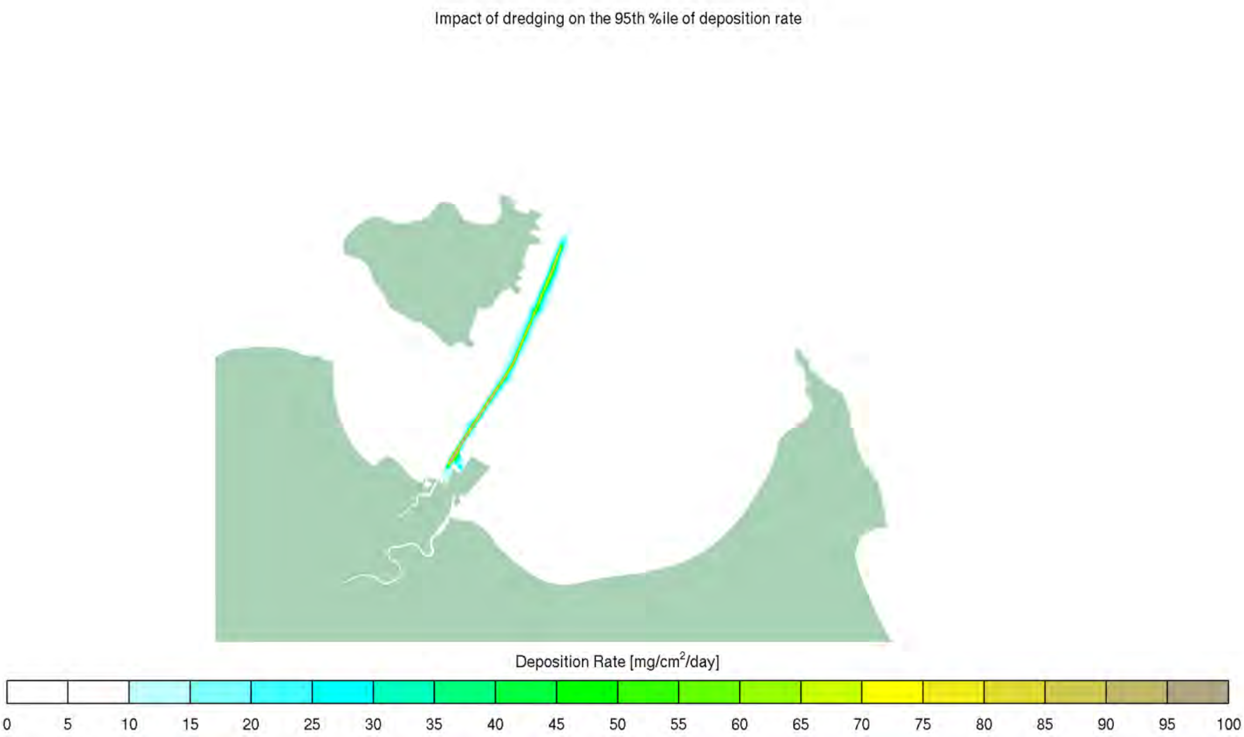


Figure 6-29 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



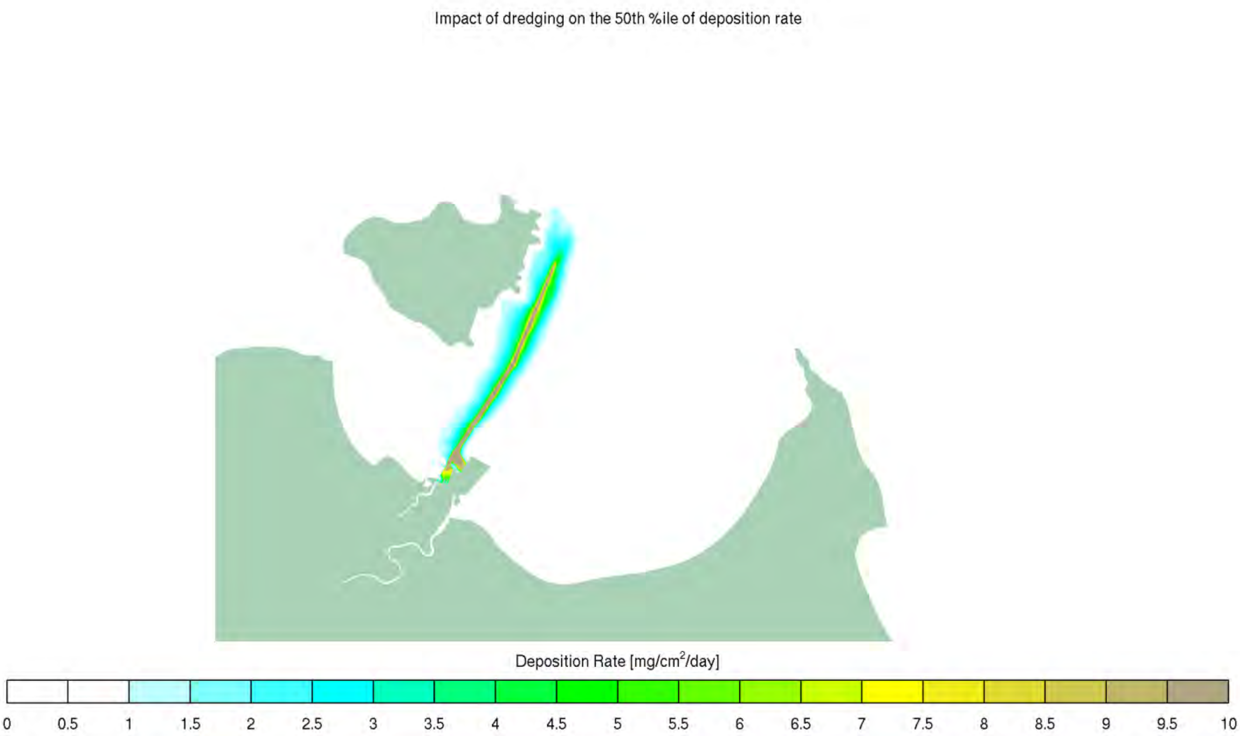


Figure 6-30 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

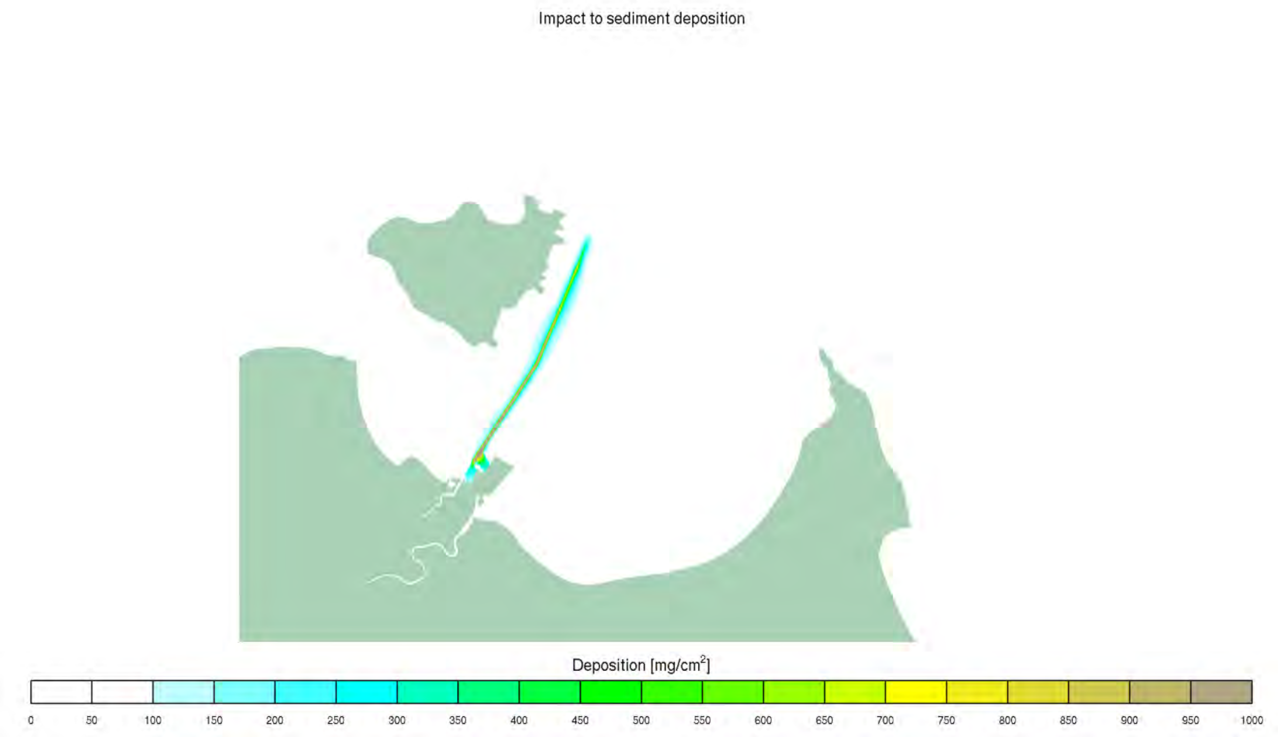
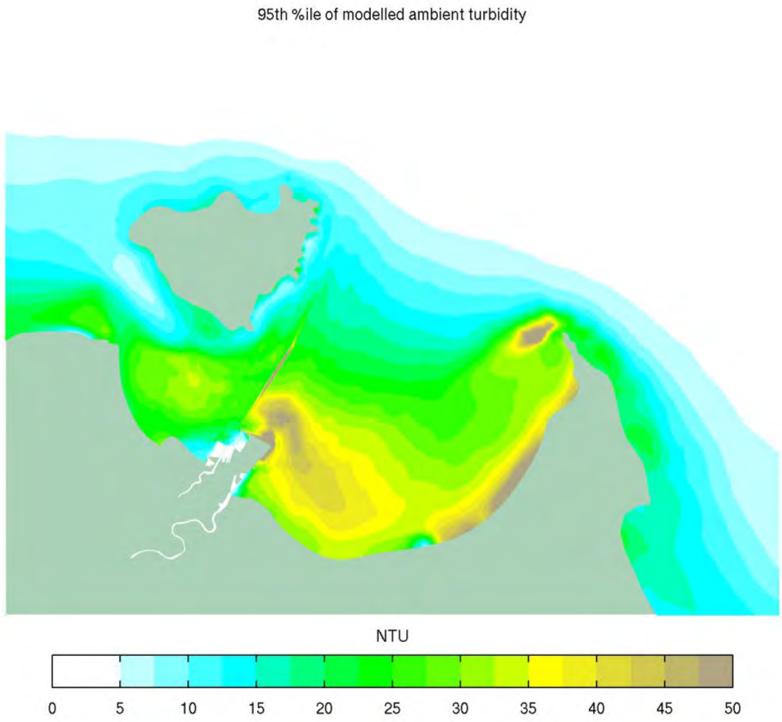


Figure 6-31 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Small TSHD - Final Deposition of Dredged Sediment After 30 Days

6.3.3.2 Deepening of Platypus and Sea Channels by Backhoe

The impacts to turbidity and deposition percentiles during Stage 3 channel deepening using a backhoe are shown in Figure 6-32 to Figure 6-37. Note that the impact plots presented here show the superposition (addition) of the impacts of a backhoe dredge working at five different locations along the shipping channel. The impacts shown are representative of a typical 30 day period of backhoe dredging at each location. The influence of dredging plumes generated by the backhoe at intermediate locations along the channel can be estimated by interpreting the plots. It can be seen that the acute and chronic impacts of the backhoe dredging operation are restricted to the immediate vicinity of the dredging location. The backhoe dredging campaign for this stage of the project is expected to take approximately two years.



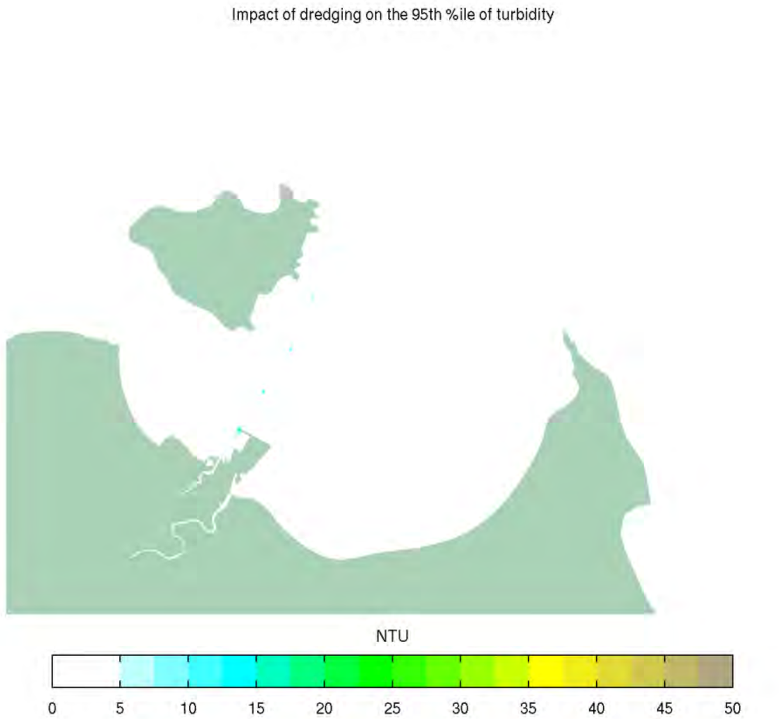
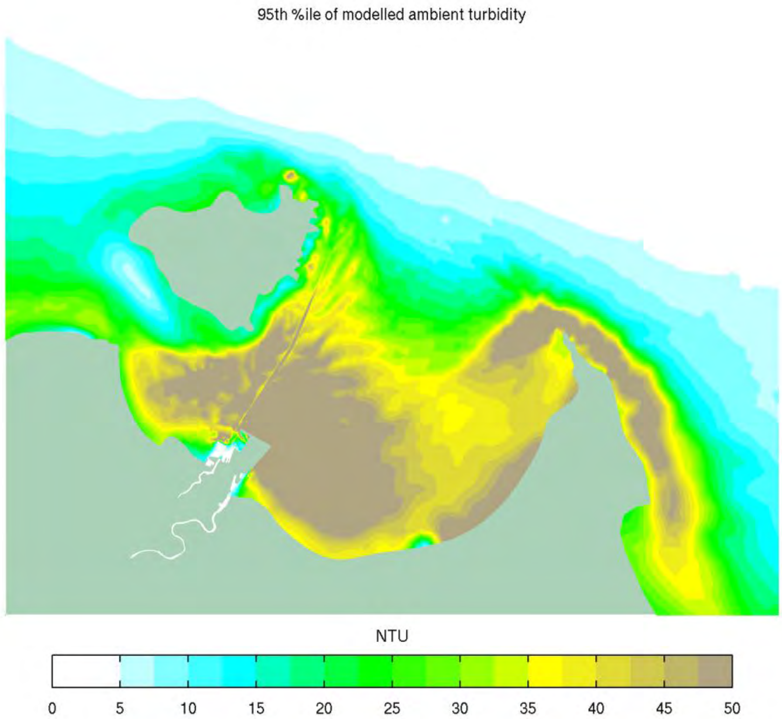


Figure 6-32 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



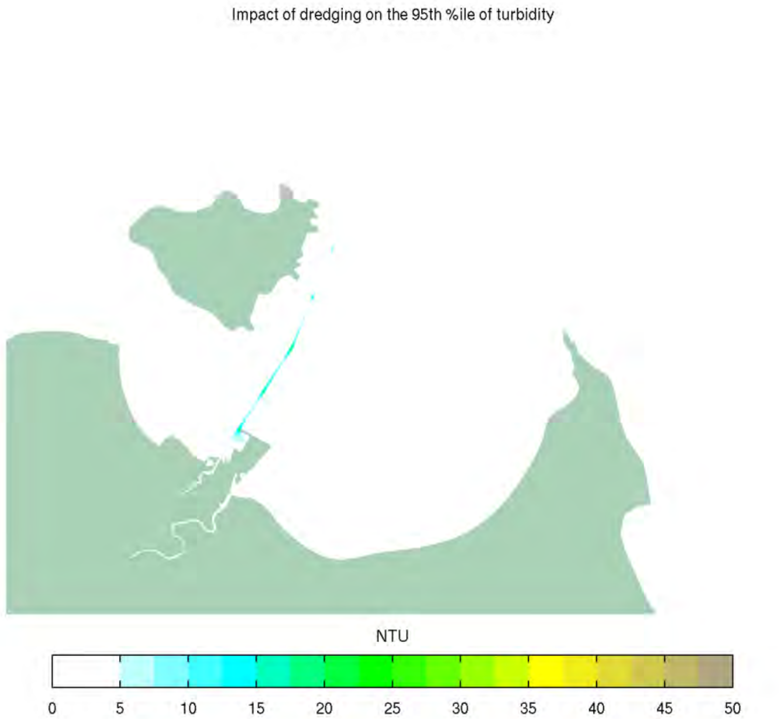


Figure 6-33 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

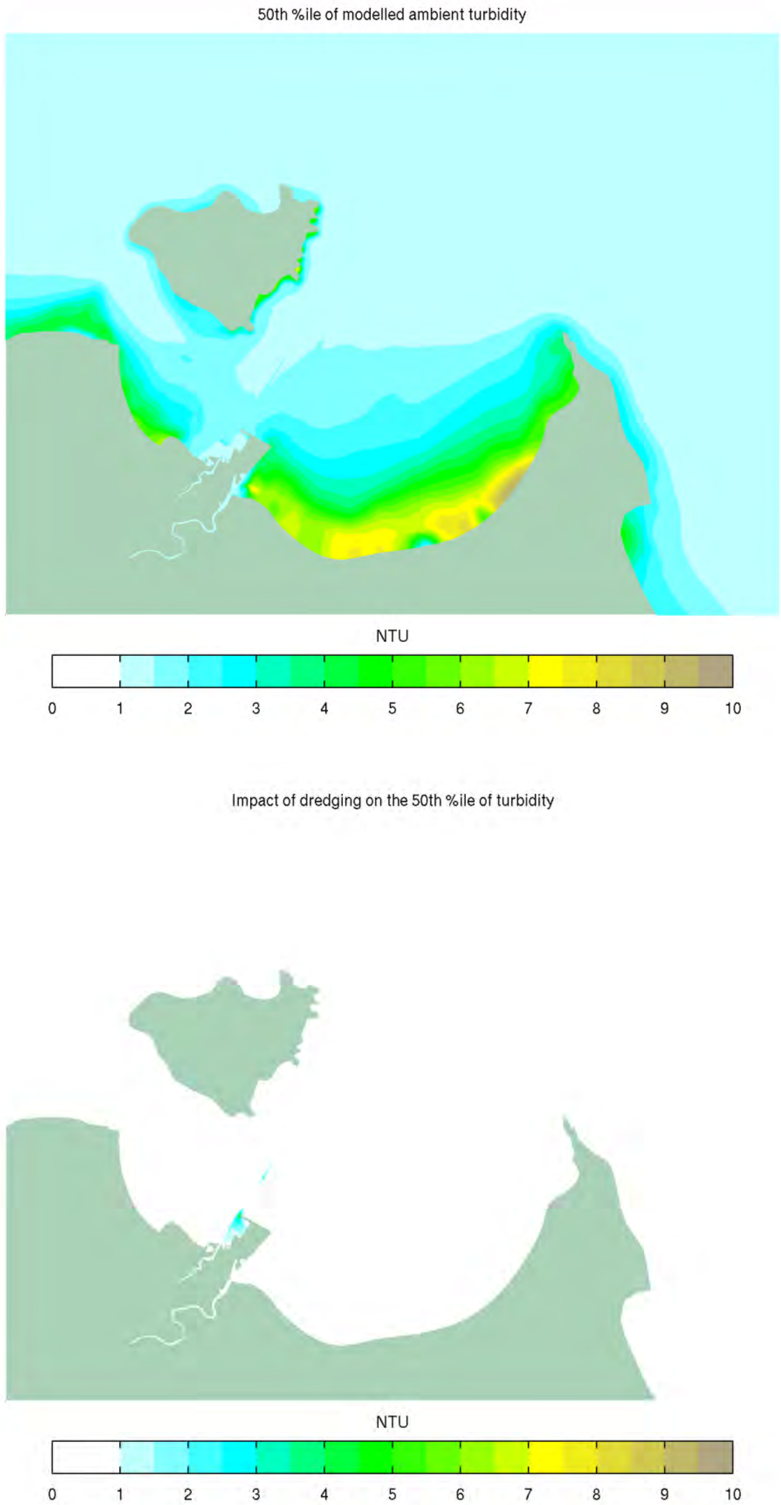


Figure 6-34 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

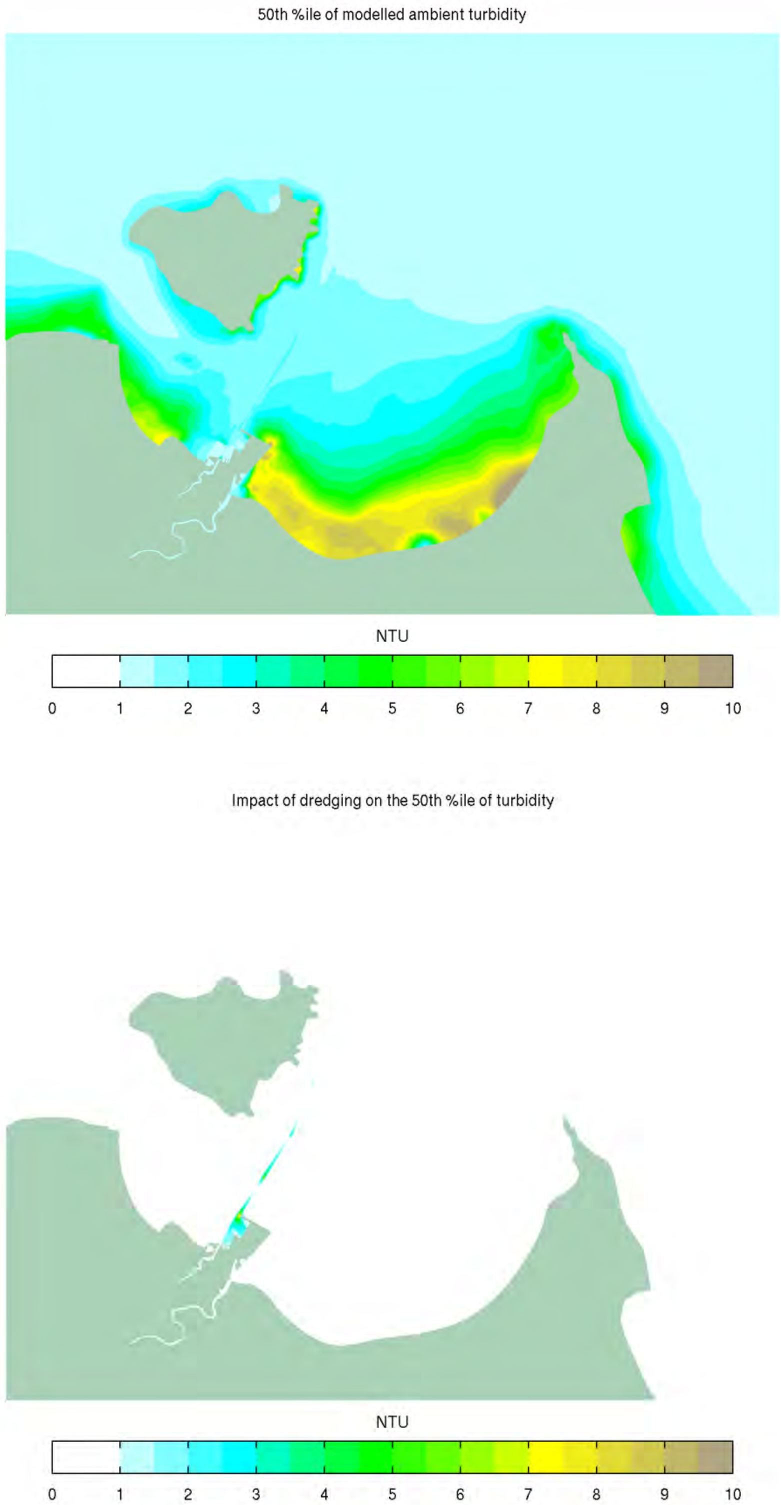


Figure 6-35 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

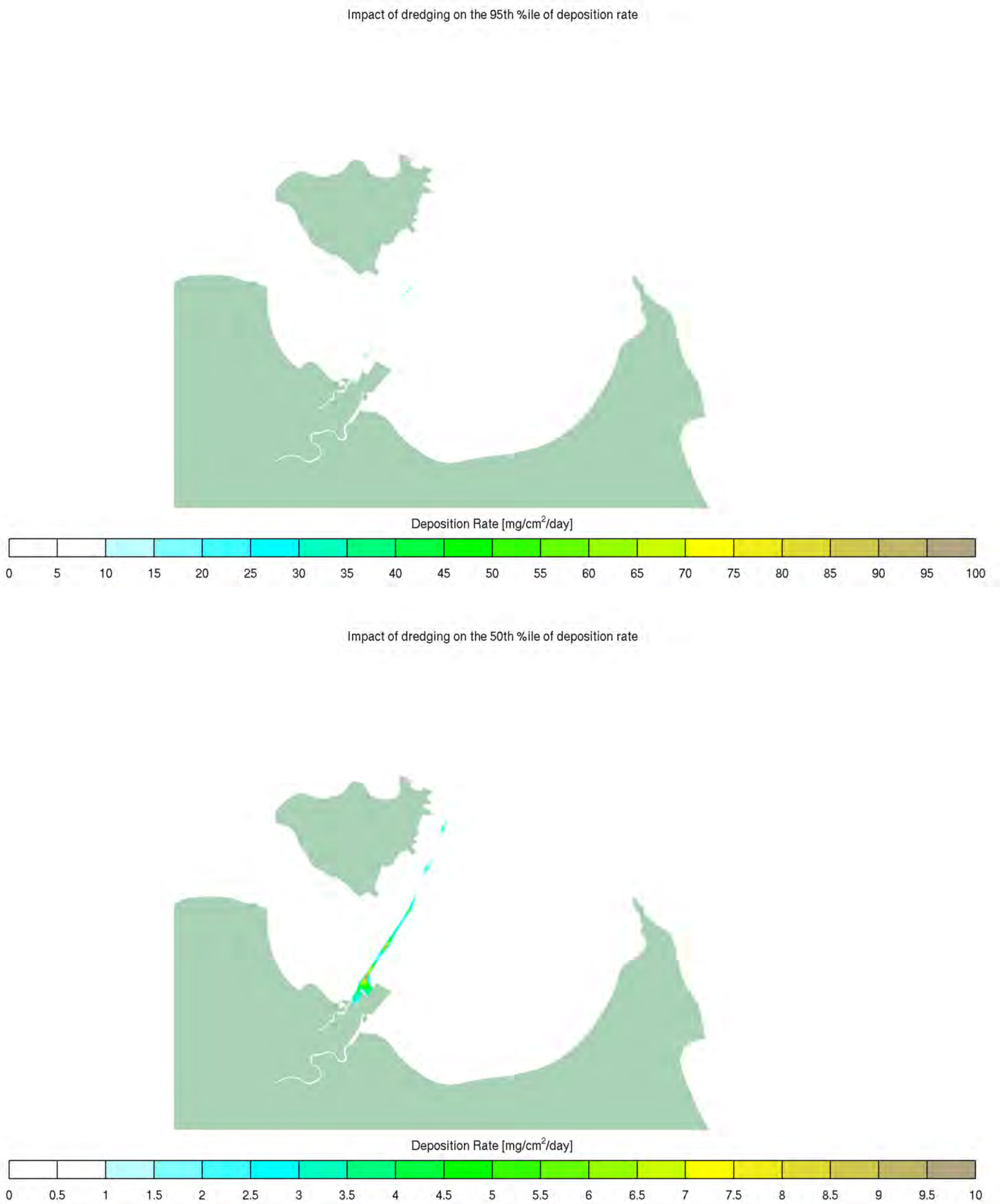


Figure 6-36 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

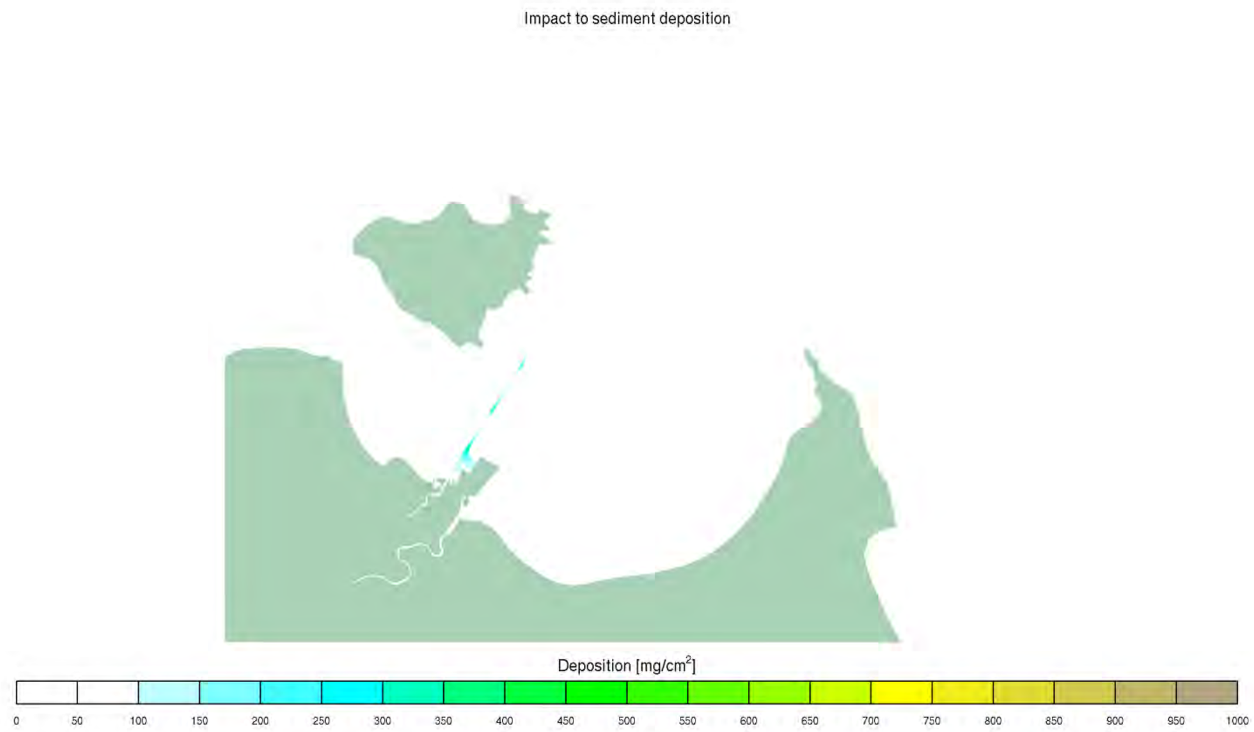


Figure 6-37 Stage 3 Dredging – Deepening of Platypus and Sea Channels by Backhoe - Final Deposition of Dredged Sediment After 30 Days (Five Locations)

6.4 'Worst Case' Dredging Impacts

The 'Worst Case' dredging impacts were obtained by taking the ensemble maximum of the predicted impacts to the turbidity and deposition rates over the five 30 day TSHD dredging simulations. This means that the 'Worst Case' impacts represent the highest intensity impacts that are possible in a given location if adverse weather conditions occur.

6.4.1 Stage 1 – Channel Widening by TSHD

The potential impacts to the turbidity percentiles are a function of both the dredging activity and the ambient meteorological and hydrodynamic conditions. Examples of the impacts to the 95^{th} percentile turbidity for each of the five 30 day modelling periods are provided in Figure 6-38. The corresponding wind roses for each modelling period are provided in Figure 6-2. The months with the strongest winds (January 2010 and March 2010) show a lower overall level of impact (due to higher ambient turbidity) but a larger spatial extent (due to stronger wind-driven currents).

Figure 6-39 shows the maximum change in the 95th percentile depth-averaged turbidity due to dredging throughout the modelling domain over the five different 30-day modelling periods. Figure 6-40 shows the change in the 95^{th} percentile turbidity in the bottom 1m layer of the model due to dredging (again, the maximum of the five 30-day periods that were modelled). These figures indicate the possible variability of acute (short term) influence of suspended sediment plumes generated by the TSHD depending on the ambient meteorological conditions.

Figure 6-41 shows the change in the 50^{th} percentile depth-averaged turbidity due to dredging and Figure 6-42 shows the change in the 50^{th} percentile turbidity in the bottom 1m layer of the model due to dredging (the maximum out of the five modelling periods). These figures indicate the possible chronic (persistent) influence of suspended sediment plumes generated by the TSHD depending on the ambient meteorological conditions.

Figure 6-43 shows the change in the 95^{th} and 50^{th} percentile deposition rate due to dredging, while Figure 6-44 shows the total amount of dredged material deposited in a 30 day simulation (the maximum of the five modelling periods).

Overall, the modelled turbidity and deposition impacts are generally limited to the immediate vicinity of the channel, although there is the potential for some sensitive receptors along the coastline of Magnetic Island to be influenced by plumes during strong easterly or southerly wind conditions.

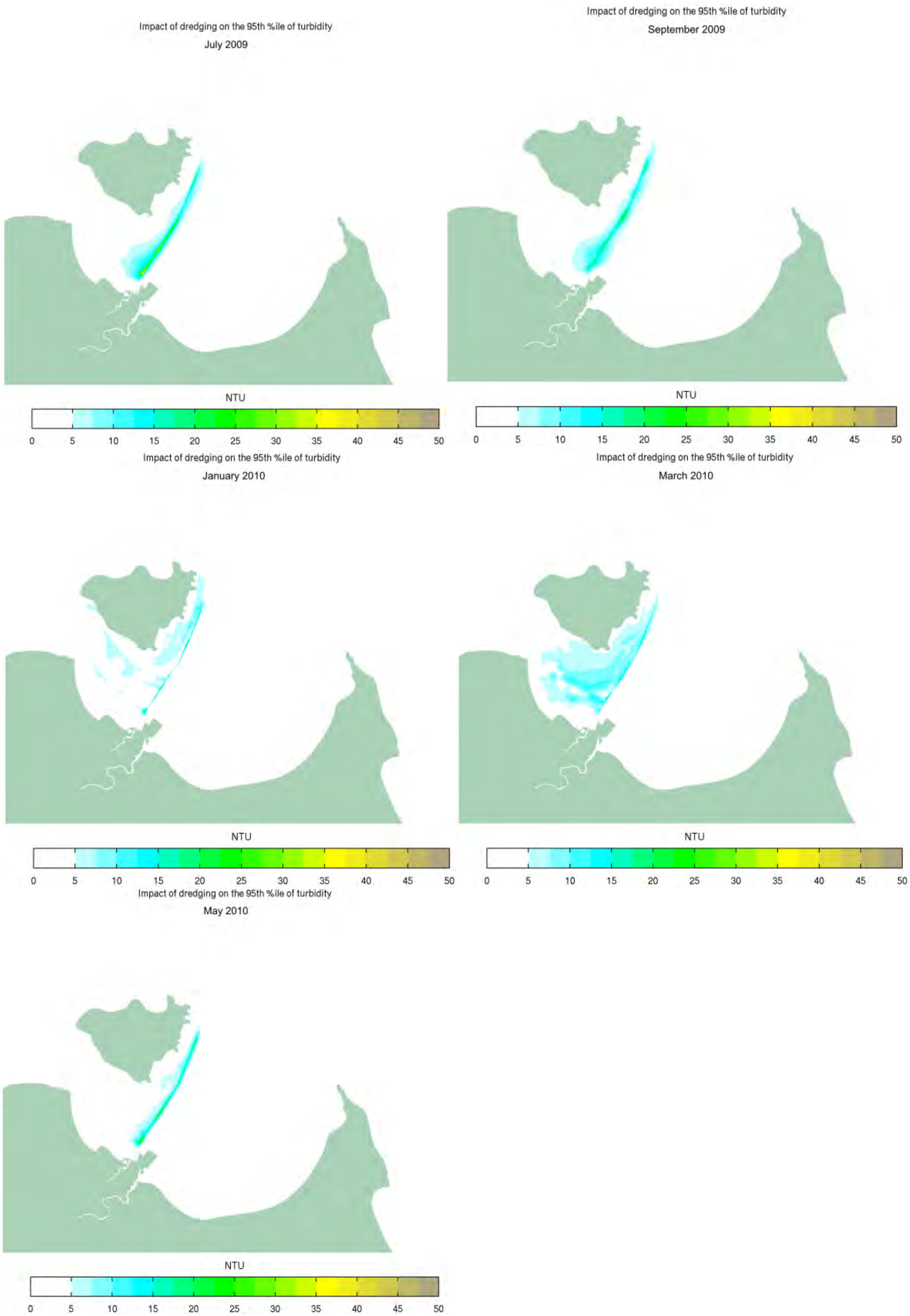


Figure 6-38 Dredging Impacts to the 95th Percentile Turbidity for each Modelling Period

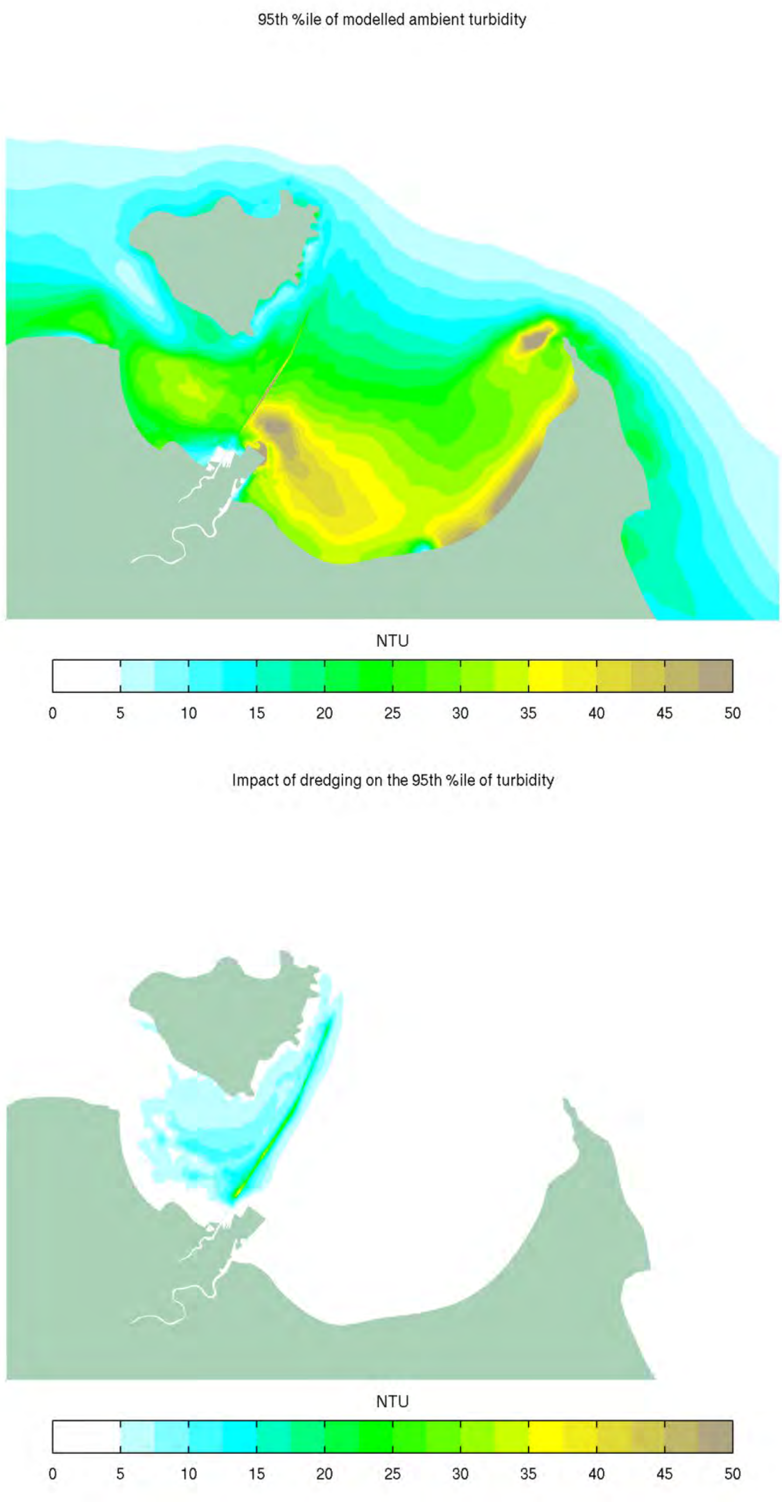
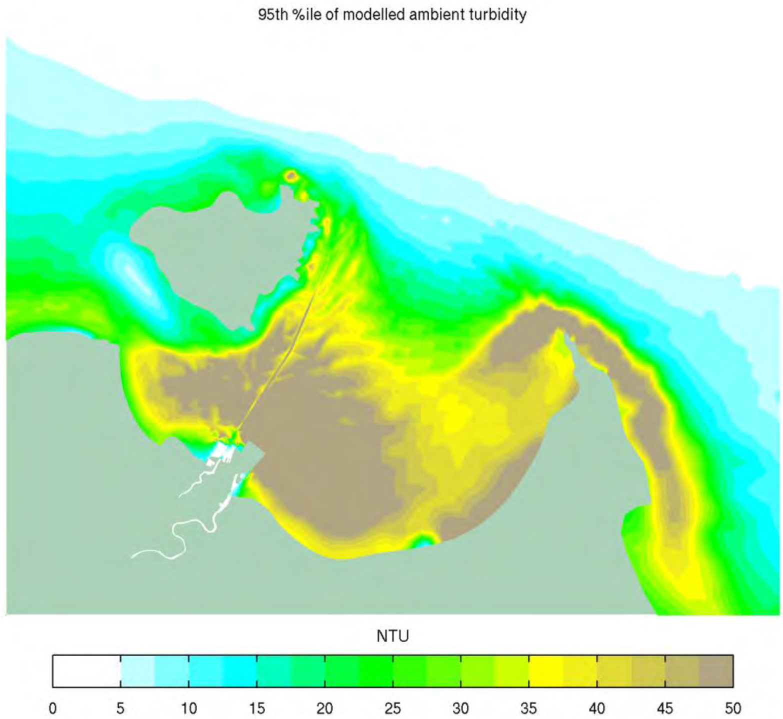


Figure 6-39 Stage 1 – ‘Worst Case’ - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



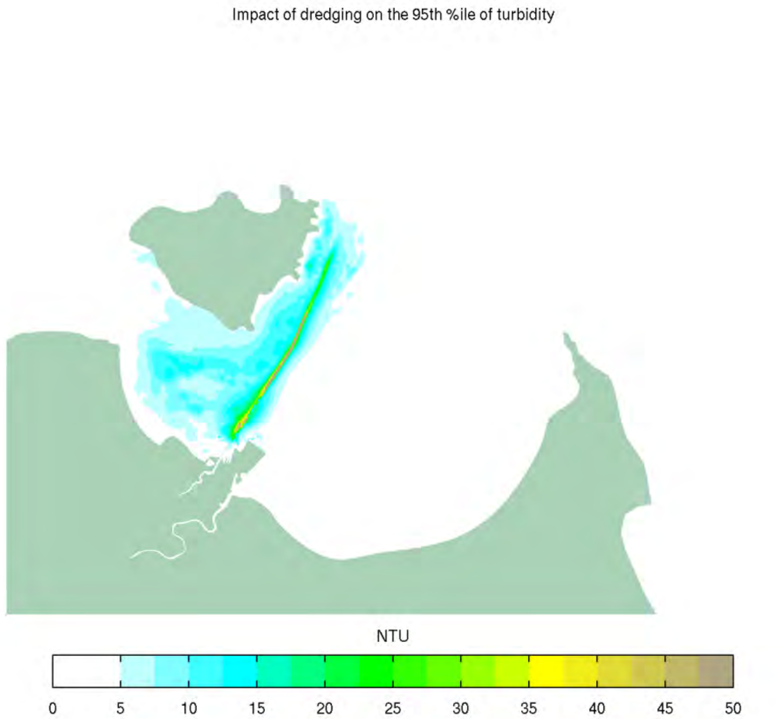


Figure 6-40 Stage 1 – 'Worst Case' - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

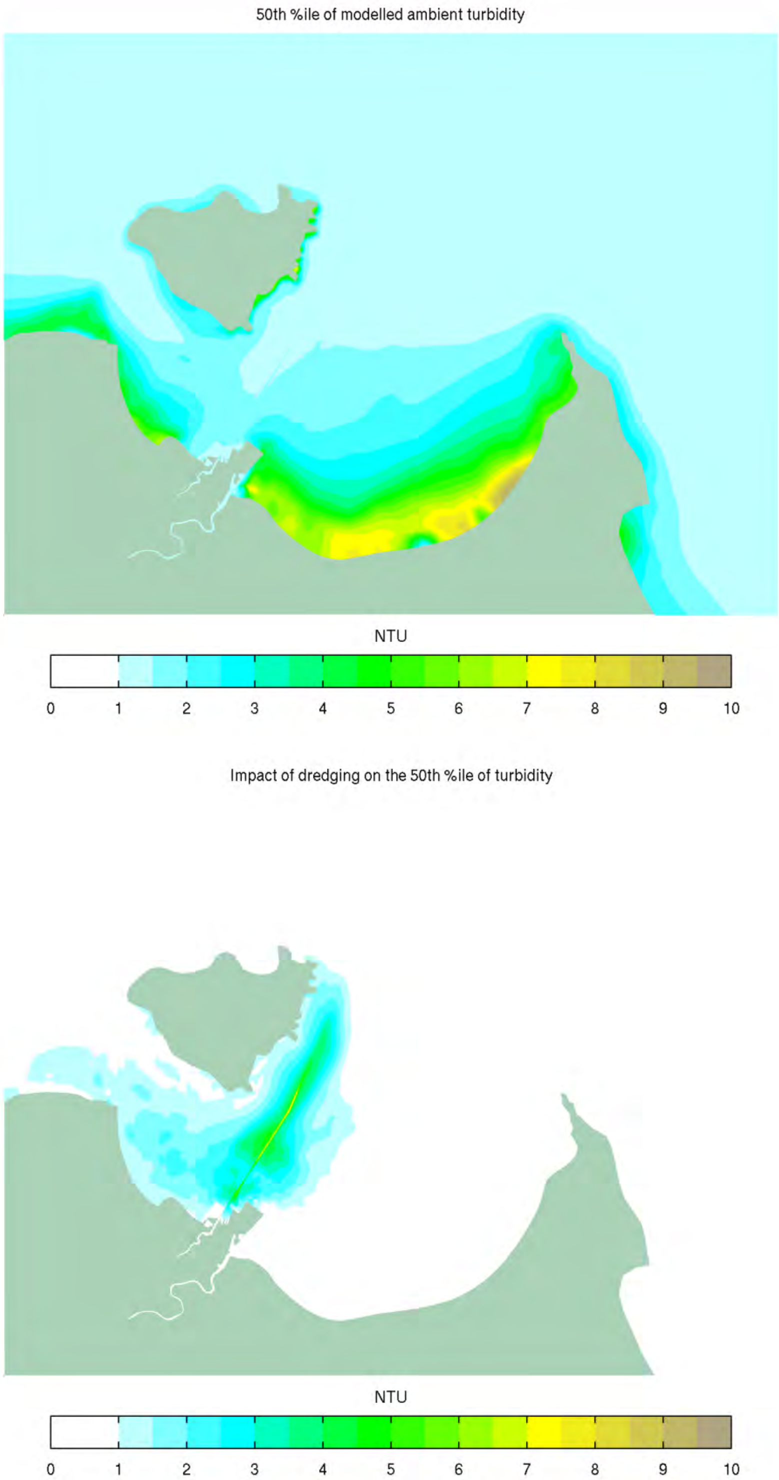
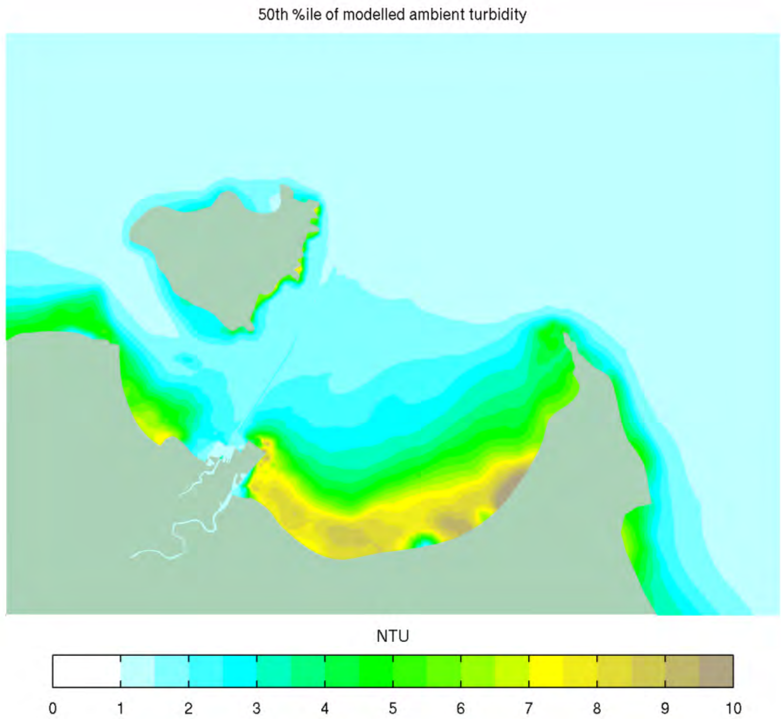


Figure 6-41 Stage 1 - 'Worst Case' - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



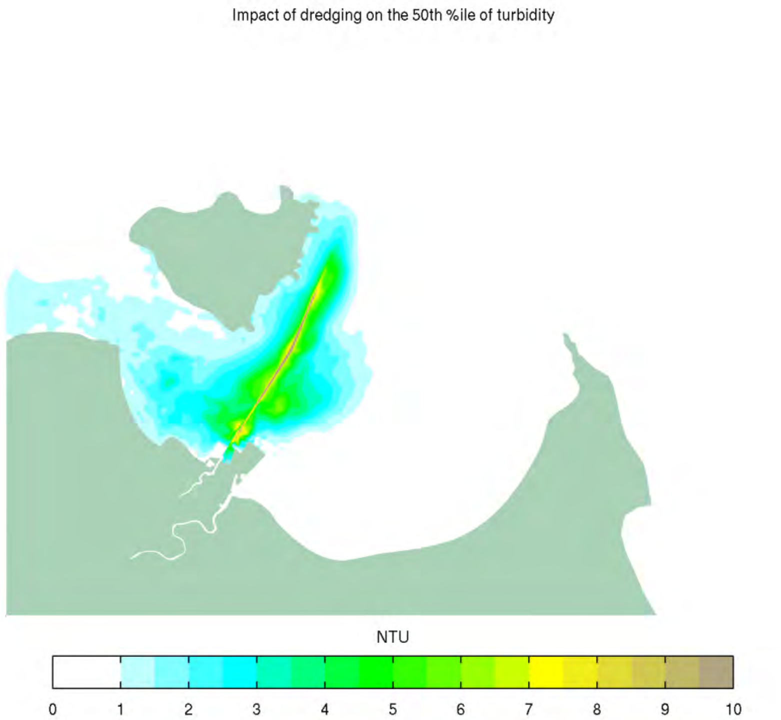
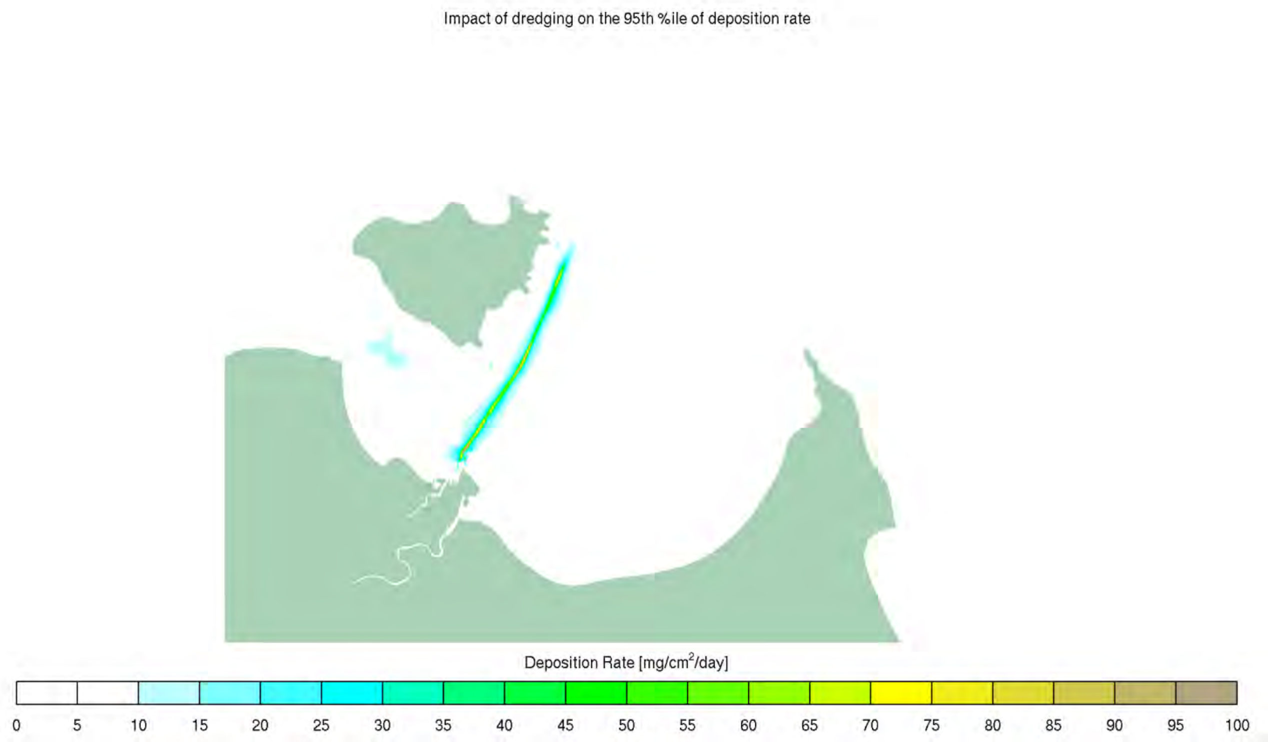


Figure 6-42 Stage 1 - 'Worst Case' - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



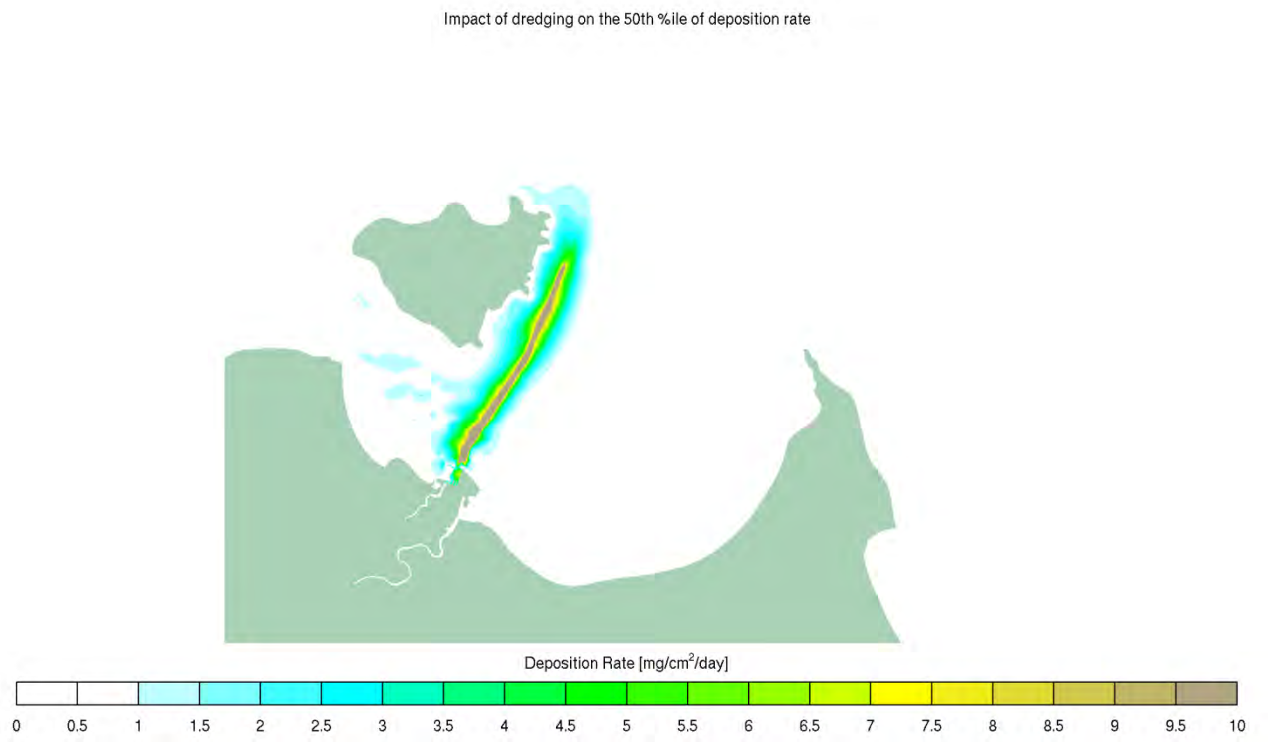


Figure 6-43 Stage 1 - 'Worst Case' - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

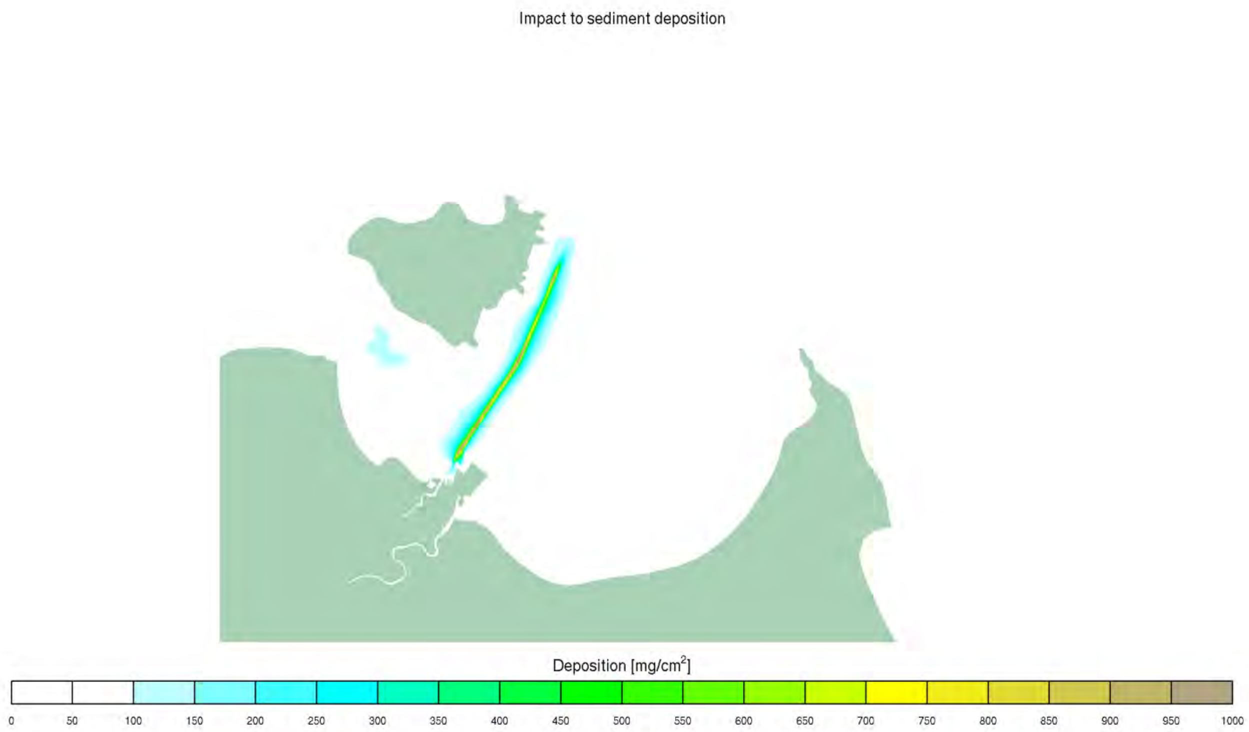


Figure 6-44 Stage 1 - 'Worst Case' - Final Deposition of Dredged Sediment

6.4.2 Stage 3 – Channel Deepening by TSHD

Figure 6-45 the maximum change in the 95th percentile depth-averaged turbidity due to dredging throughout the modelling domain over the five different 30-day modelling periods for the deepening of the channel by TSHD. Figure 6-46 shows the change in the 95th percentile turbidity in the bottom 1m layer of the model due to dredging (again, the maximum of the five 30-day periods that were modelled). These figures indicate the possible acute (short term) influence of suspended sediment plumes generated by the TSHD depending on the ambient meteorological conditions.

Figure 6-47 shows the change in the 50th percentile depth-averaged turbidity due to dredging and Figure 6-48 shows the change in the 50th percentile turbidity in the bottom 1m layer of the model due to dredging (the maximum out of the five modelling periods). These figures indicate the possible chronic (persistent) influence of suspended sediment plumes generated by the TSHD depending on the ambient meteorological conditions.

Figure 6-49 shows the change in the 95th and 50th percentile deposition rate due to dredging, while Figure 6-50 shows the total amount of dredged material deposited in a 30 day simulation (the maximum of the five modelling periods).

Overall, the modelled turbidity and deposition impacts are generally limited to the immediate vicinity of the channel, although there is the potential for some sensitive receptors along the coastline of Magnetic Island to be influenced by plumes during strong easterly or southerly wind conditions.

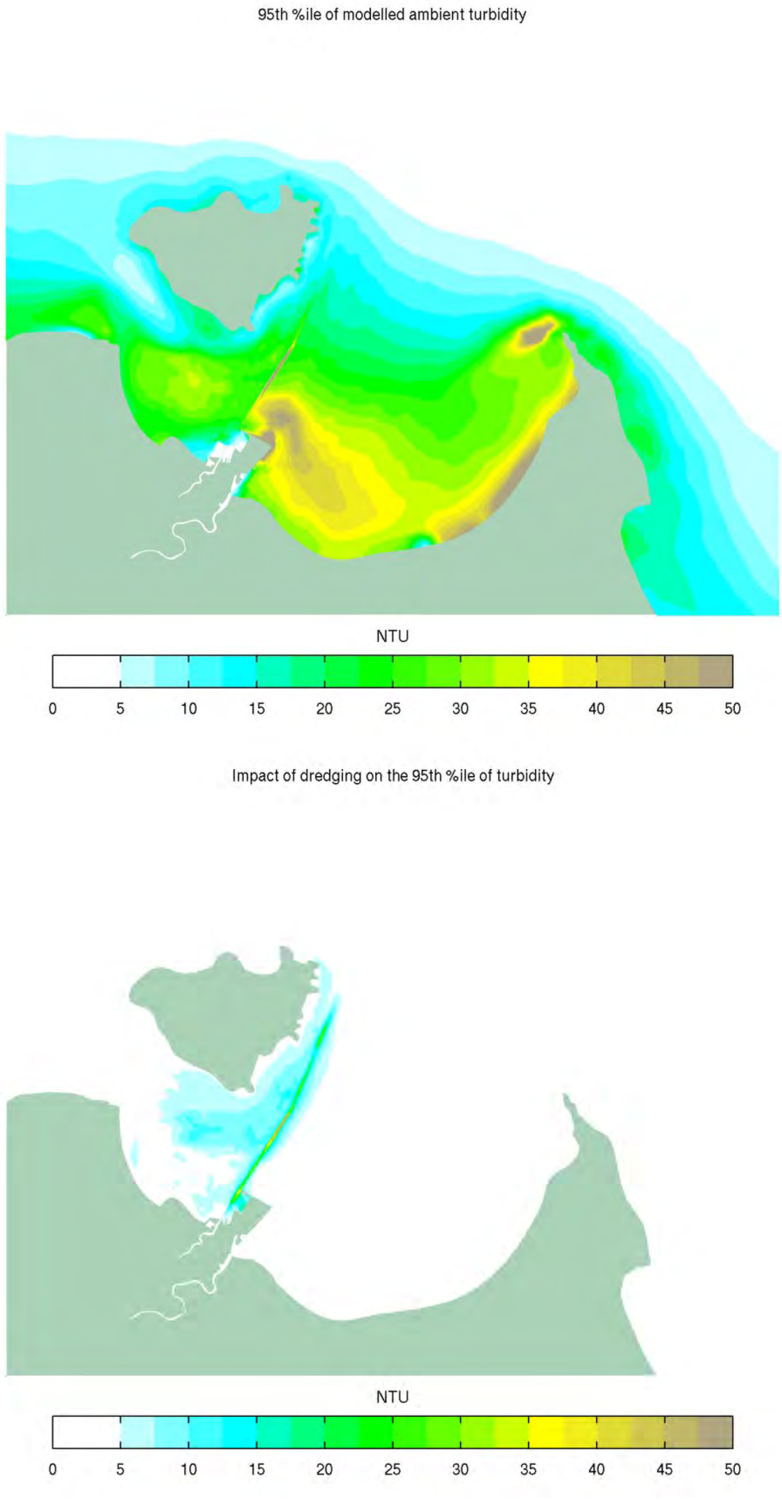


Figure 6-45 Stage 3 – 'Worst Case' - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

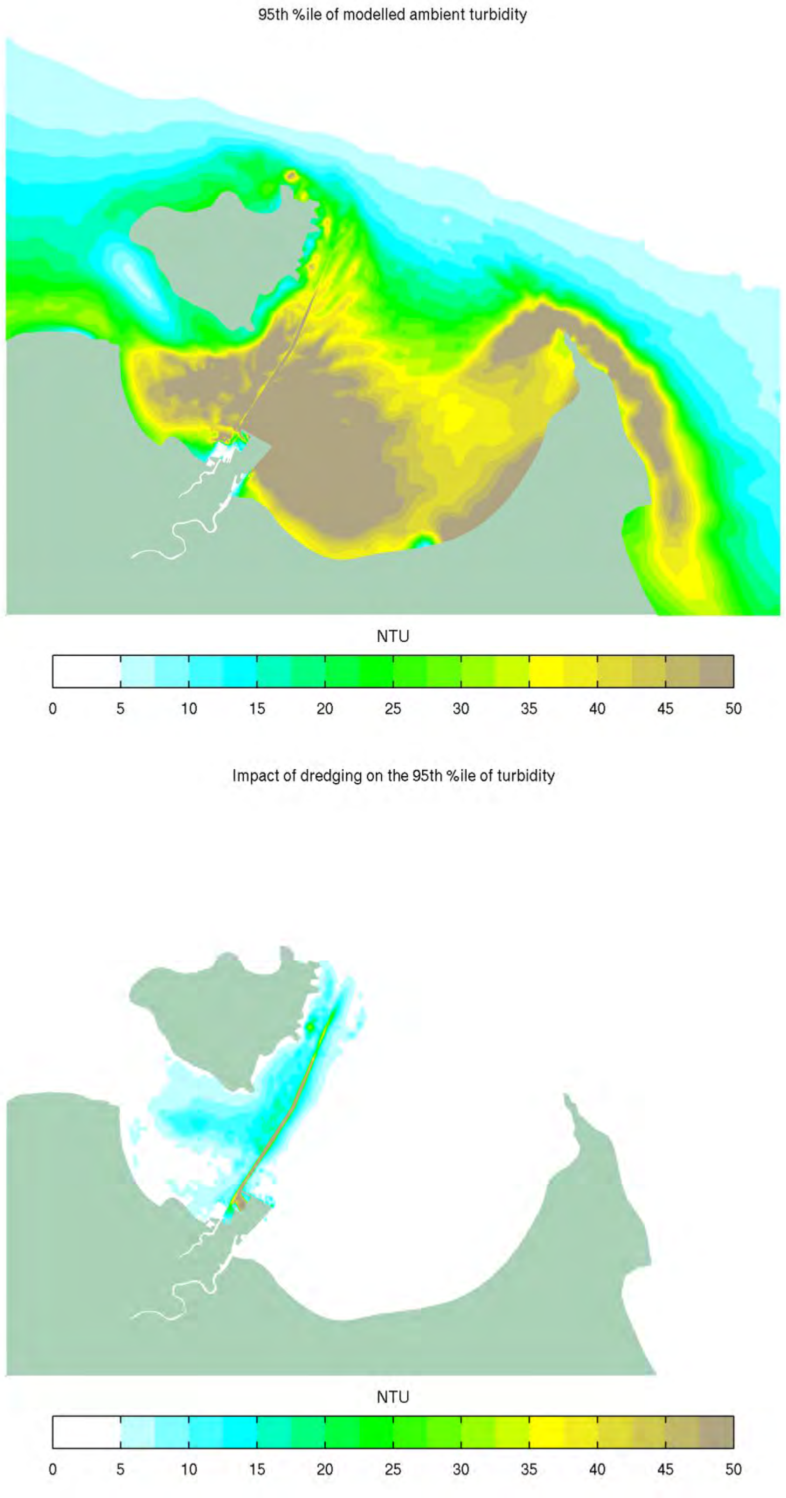
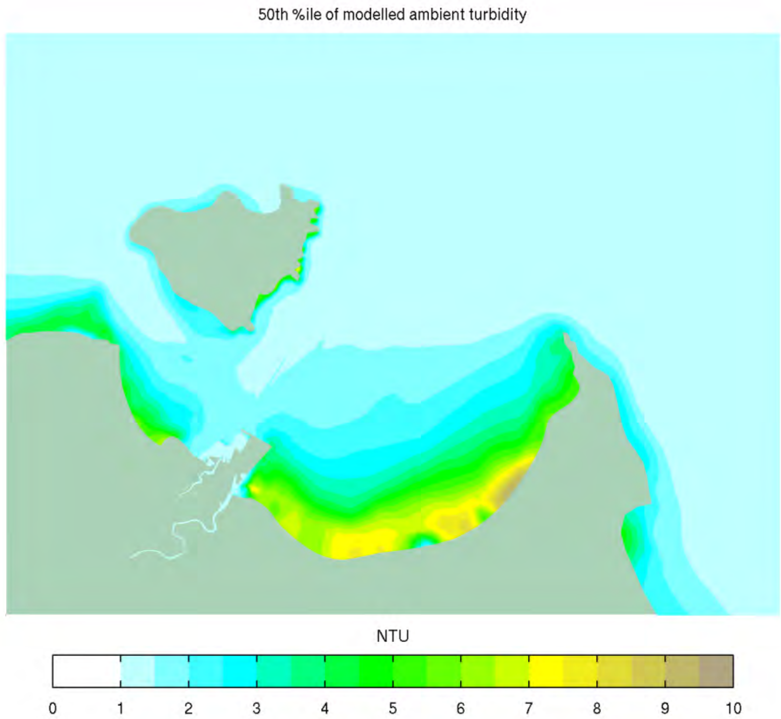


Figure 6-46 Stage 3 – 'Worst Case' - 95th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



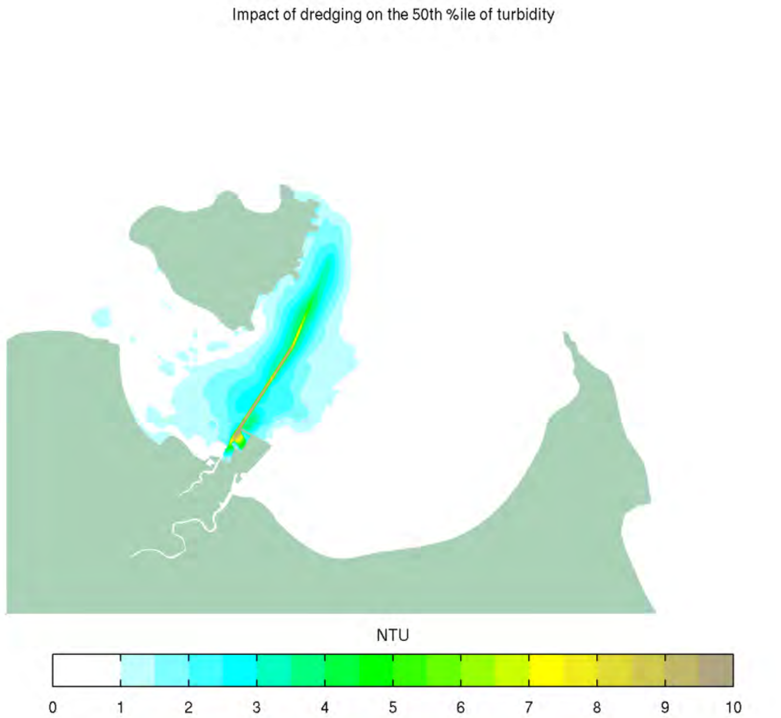
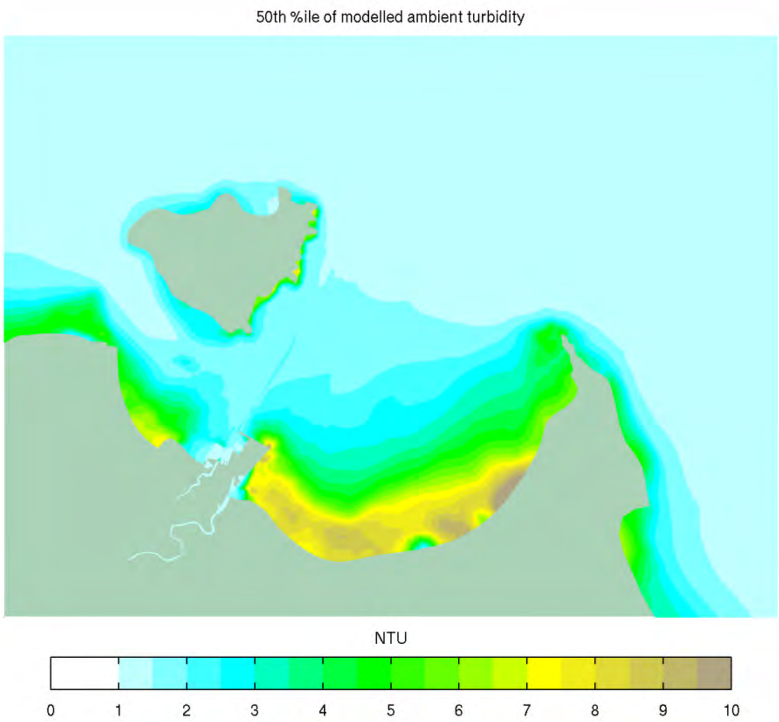


Figure 6-47 Stage 3 – 'Worst Case' - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



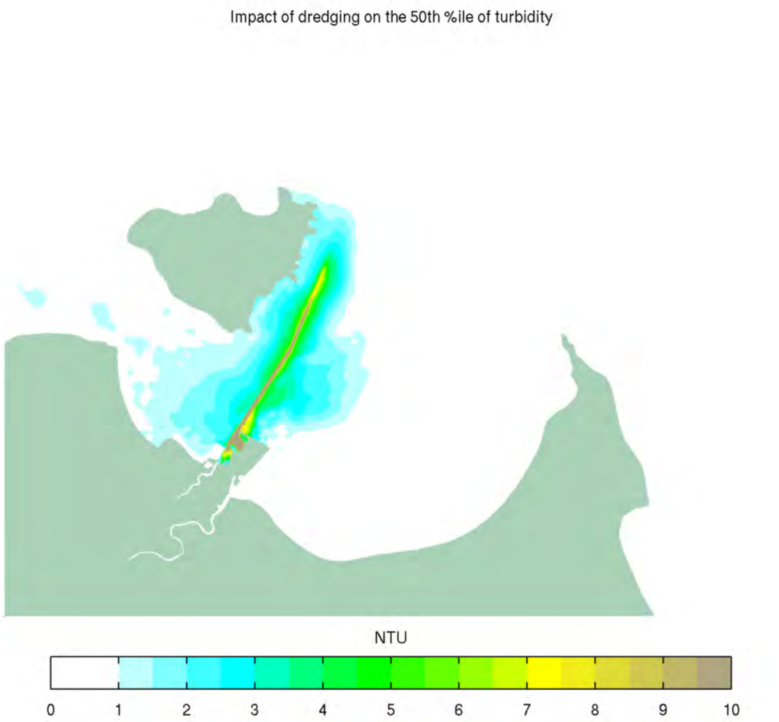
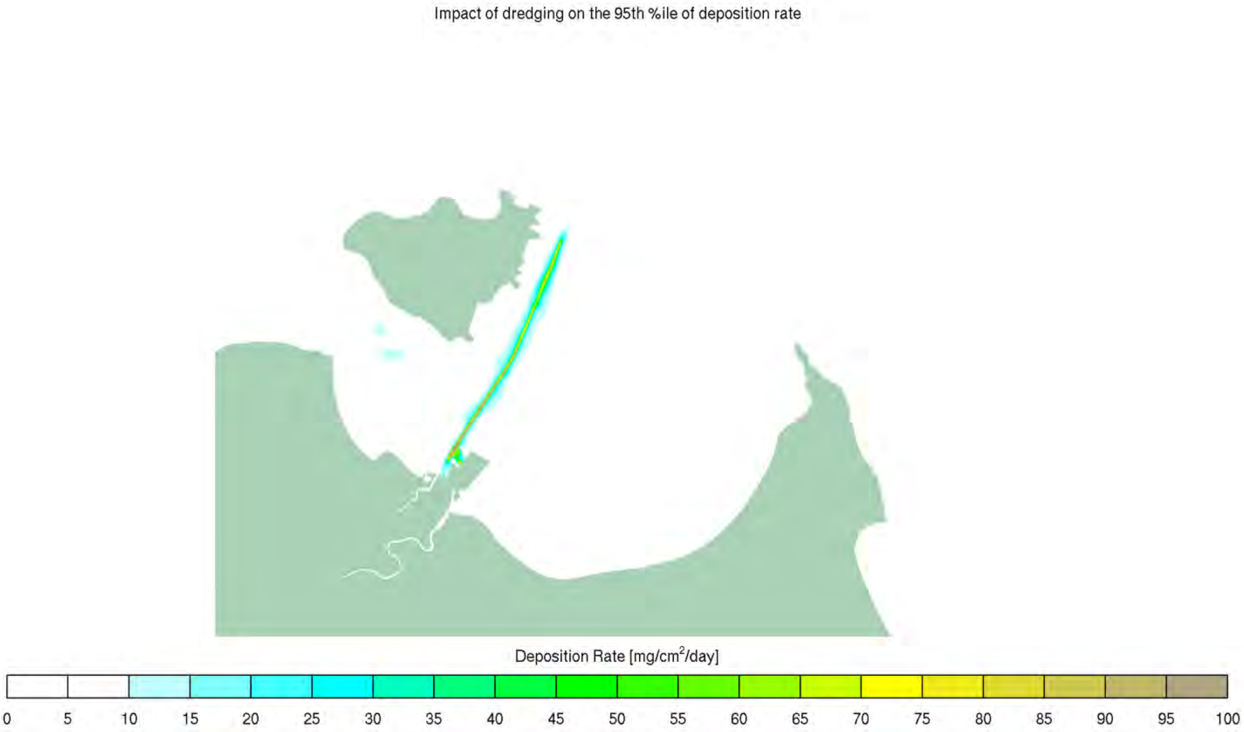


Figure 6-48 Stage 3 – 'Worst Case' - 50th Percentile Bottom 1m Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)



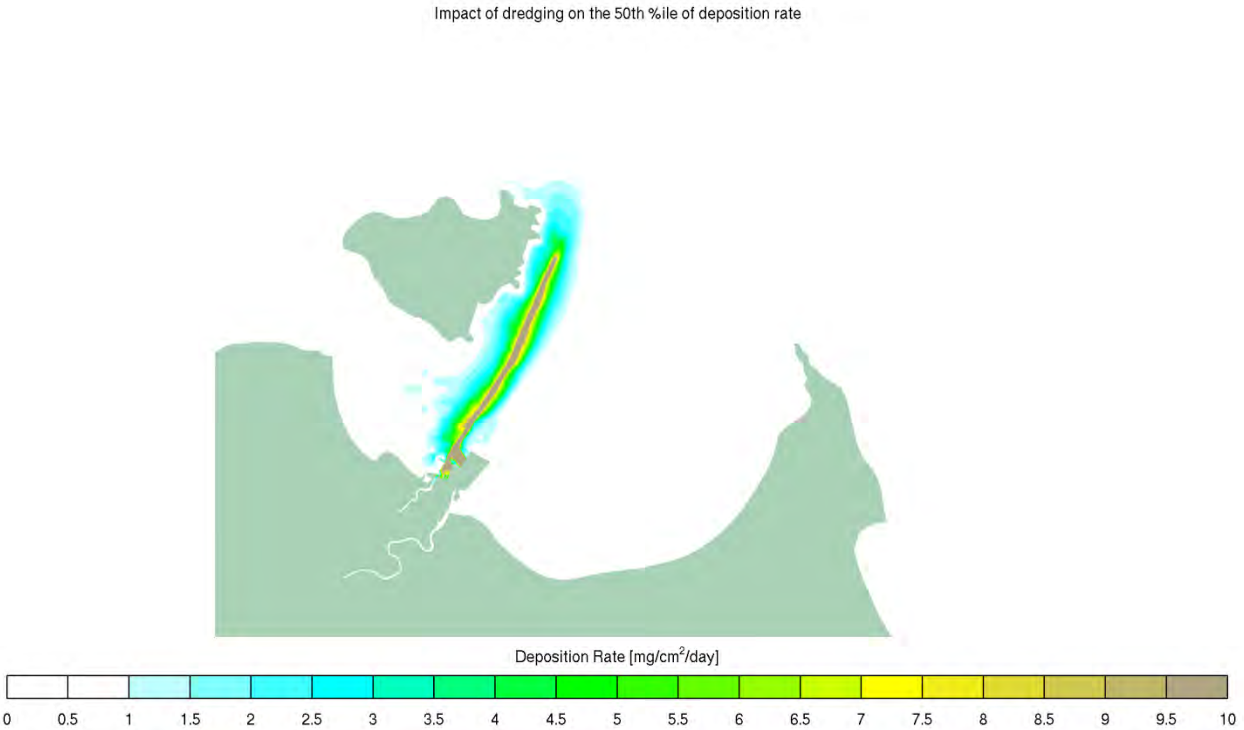


Figure 6-49 Stage 3 – 'Worst Case' - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

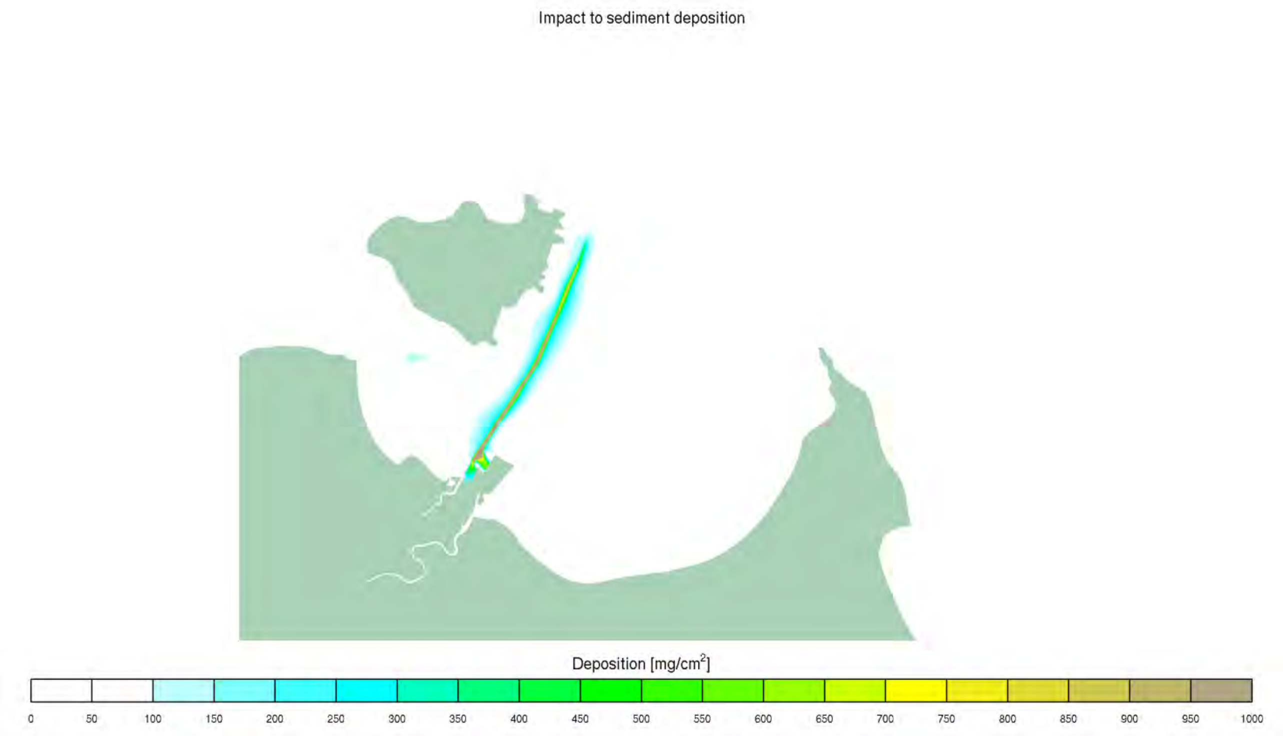


Figure 6-50 Stage 3 – 'Worst Case' - Final Deposition of Dredged Sediment After 30 Days

6.5 Maintenance Dredging Program

The modelled impact of maintenance dredging of the Platypus and Sea Channel for the Ultimate Case development is shown in Figure 6-51 to Figure 6-54. Turbidity and deposition impacts are generally limited to the immediate vicinity of the channel and the DMPA site.

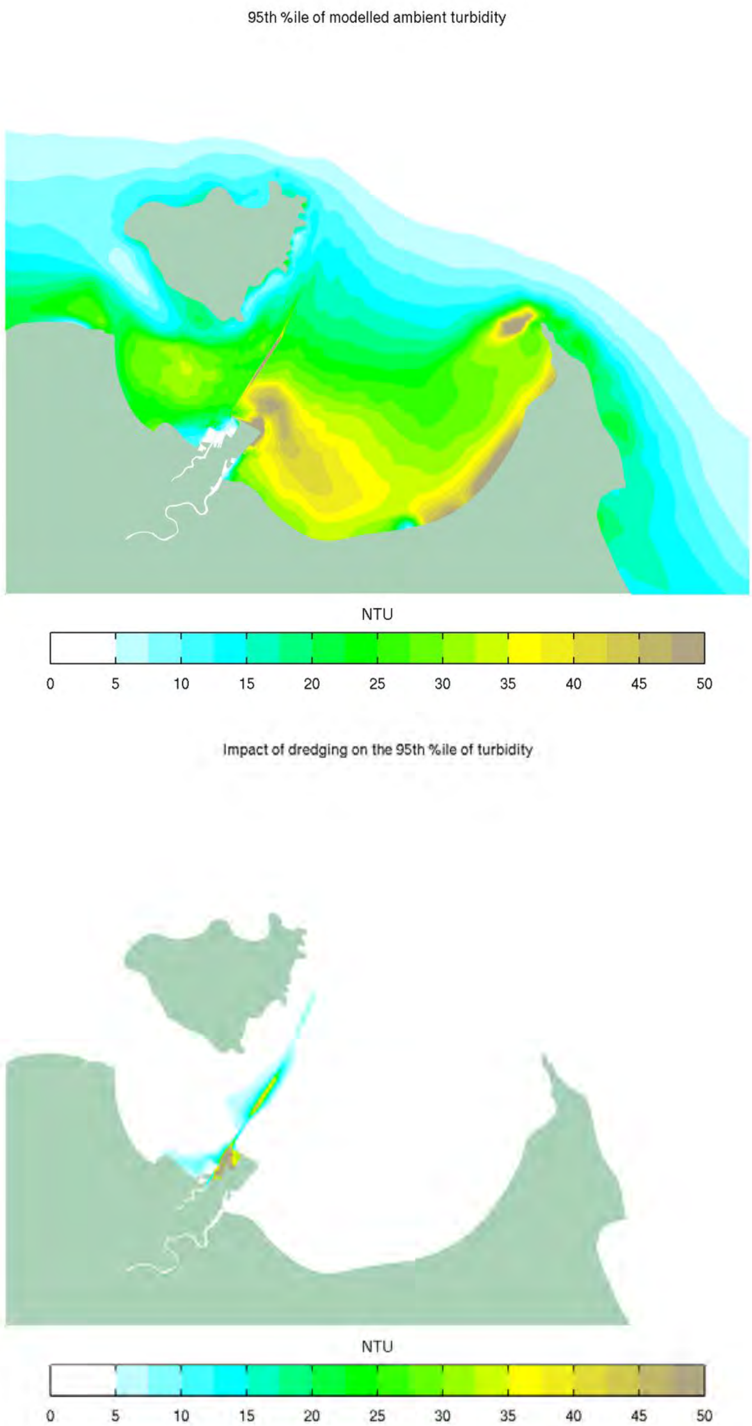


Figure 6-51 Maintenance Campaign by Small TSHD - 95th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

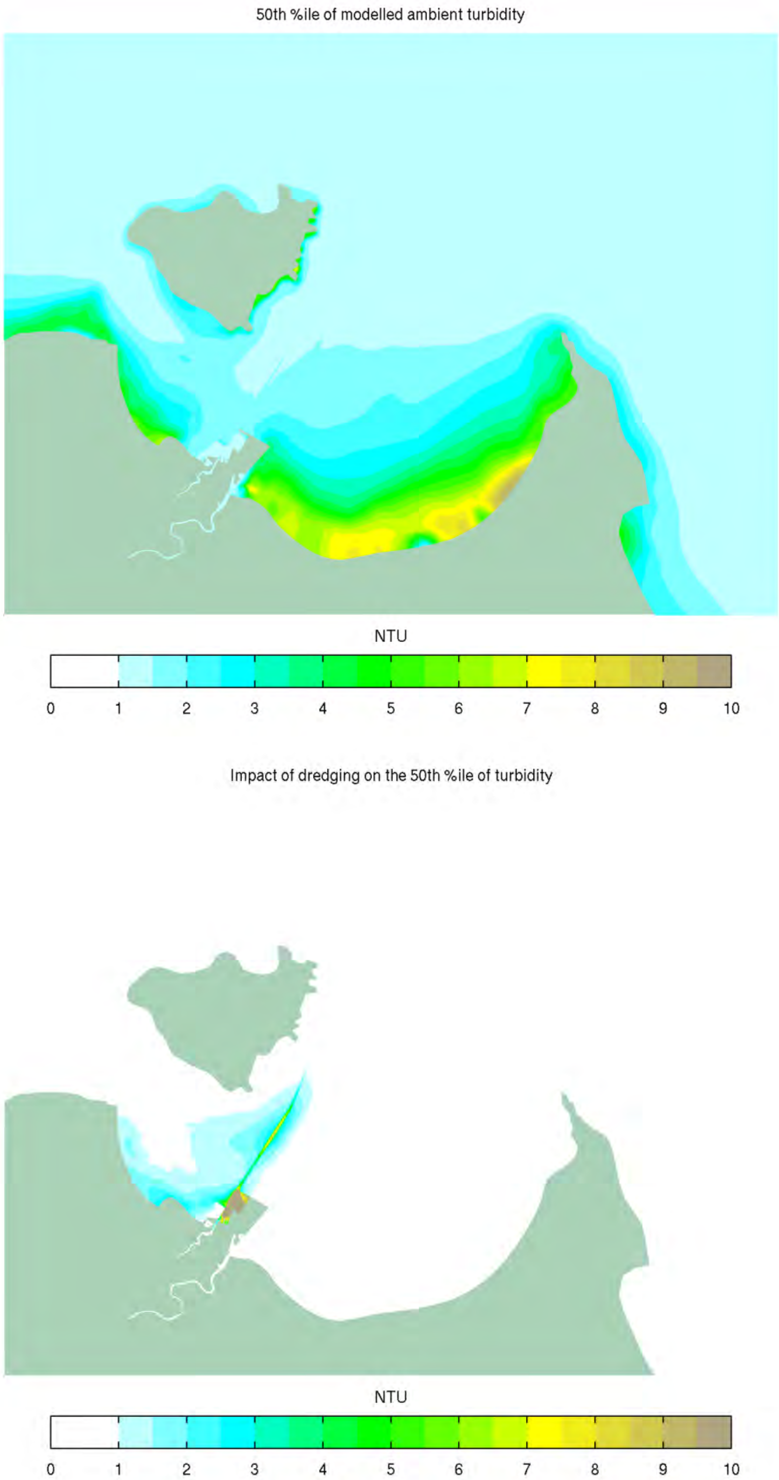


Figure 6-52 Maintenance Campaign by Small TSHD - 50th Percentile Depth Average Turbidity: Average Ambient Turbidity (top), Impact of Dredging (bottom)

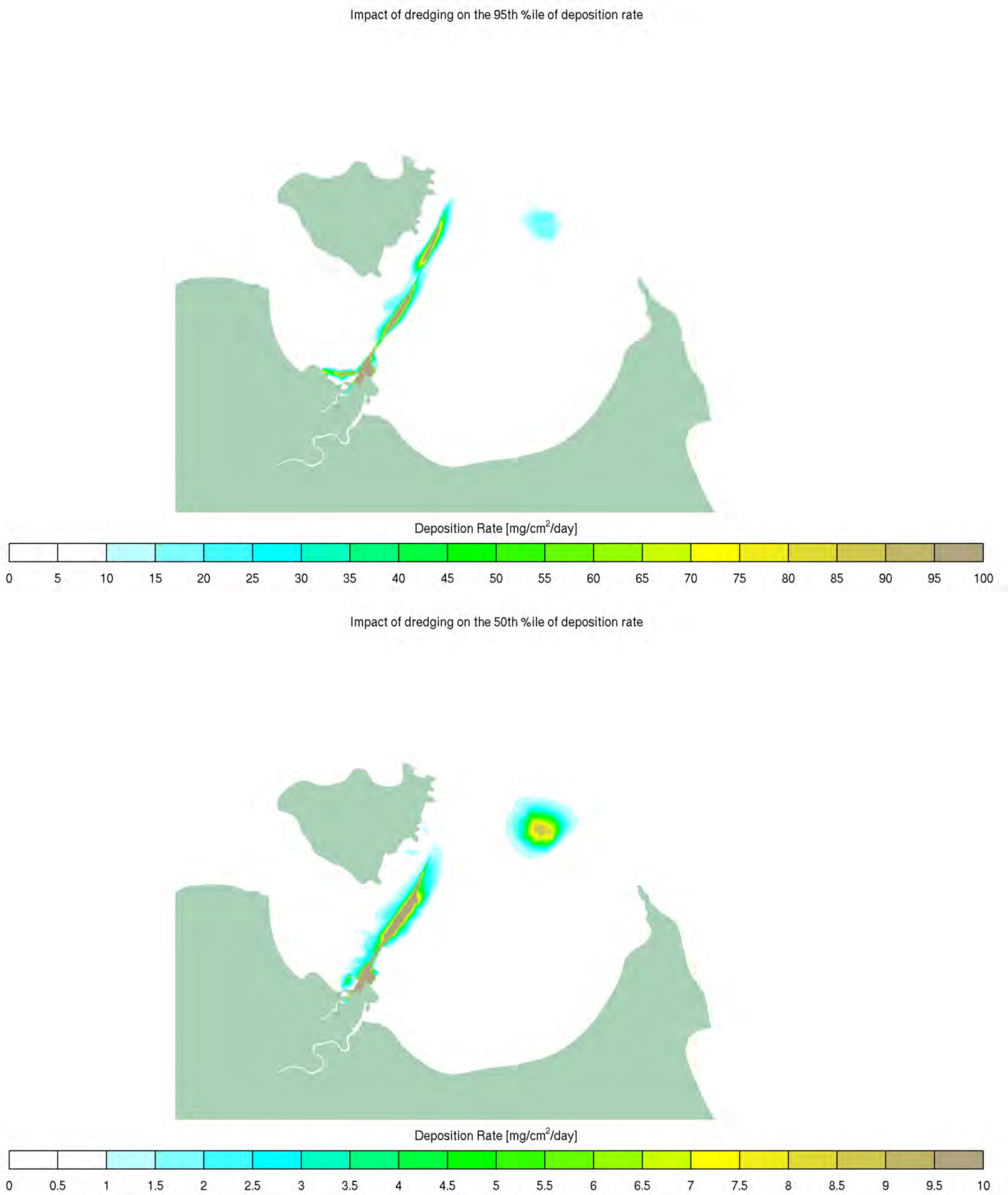


Figure 6-53 Maintenance Campaign by Small TSHD - Impact of Dredging on 95th Percentile Deposition Rate (top), Impact of Dredging on 50th Percentile Deposition Rate (bottom)

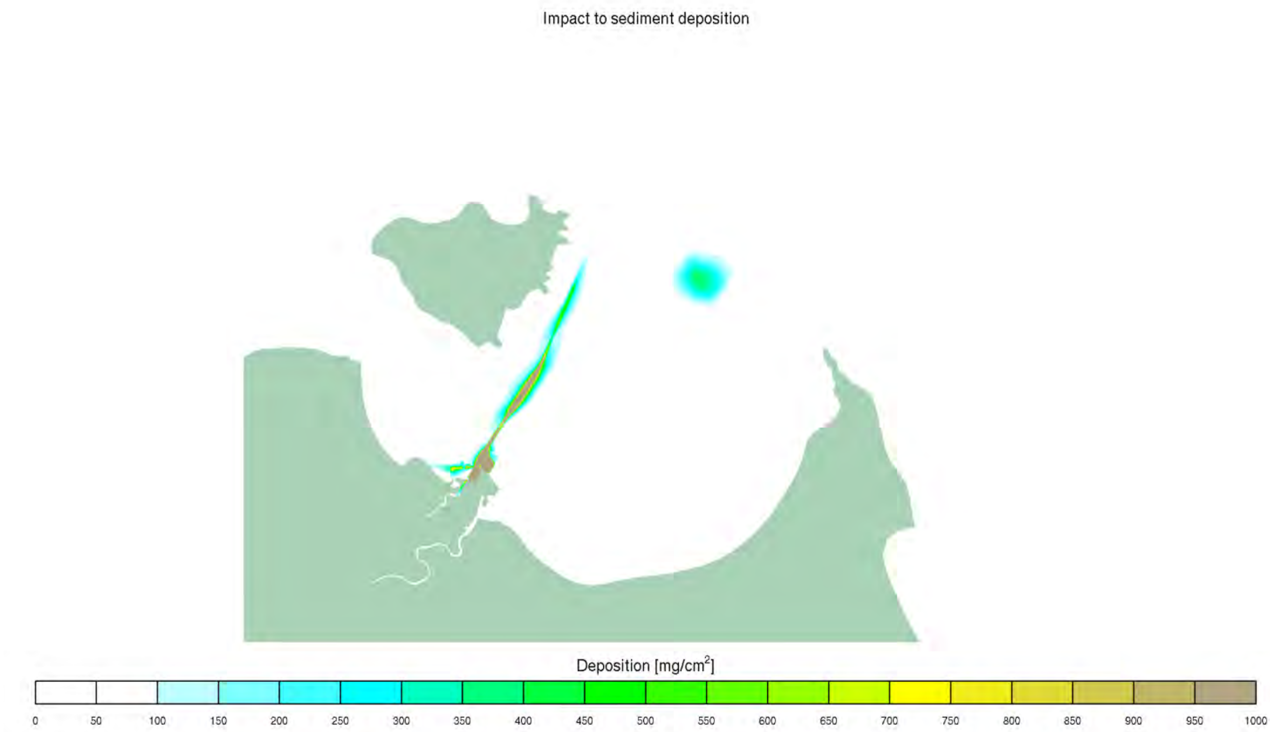


Figure 6-54 Maintenance Campaign by Small TSHD - Final Deposition of Dredged Sediment

6.6 Summary of Plume Dispersion Results

The dredge plume modelling results were used to inform the assessment of water quality and ecological impacts as discussed in the Water Quality and Marine Ecology sections of the AEIS. A full discussion of the impact of dredging plumes on water quality and marine flora and fauna can be found in those sections.

In general terms the largest impact from dredging operations is predicted to occur during the widening (Stage 1) and deepening (Stage 3) of the Platypus and Sea Channels. The entrainment of sediment by overflow of the TSHD hopper and propeller wash produces plumes which can under certain conditions influence sensitive receptor sites along the periphery of Magnetic Island.

The plumes caused by dredging in the outer harbour and caused by tailwater discharge are predicted to cause an impact at the local level but do not disperse over a wide area. The increase in suspended sediment concentrations at sensitive receptor sites from dredge plumes produced at these locations is negligible.

7 References

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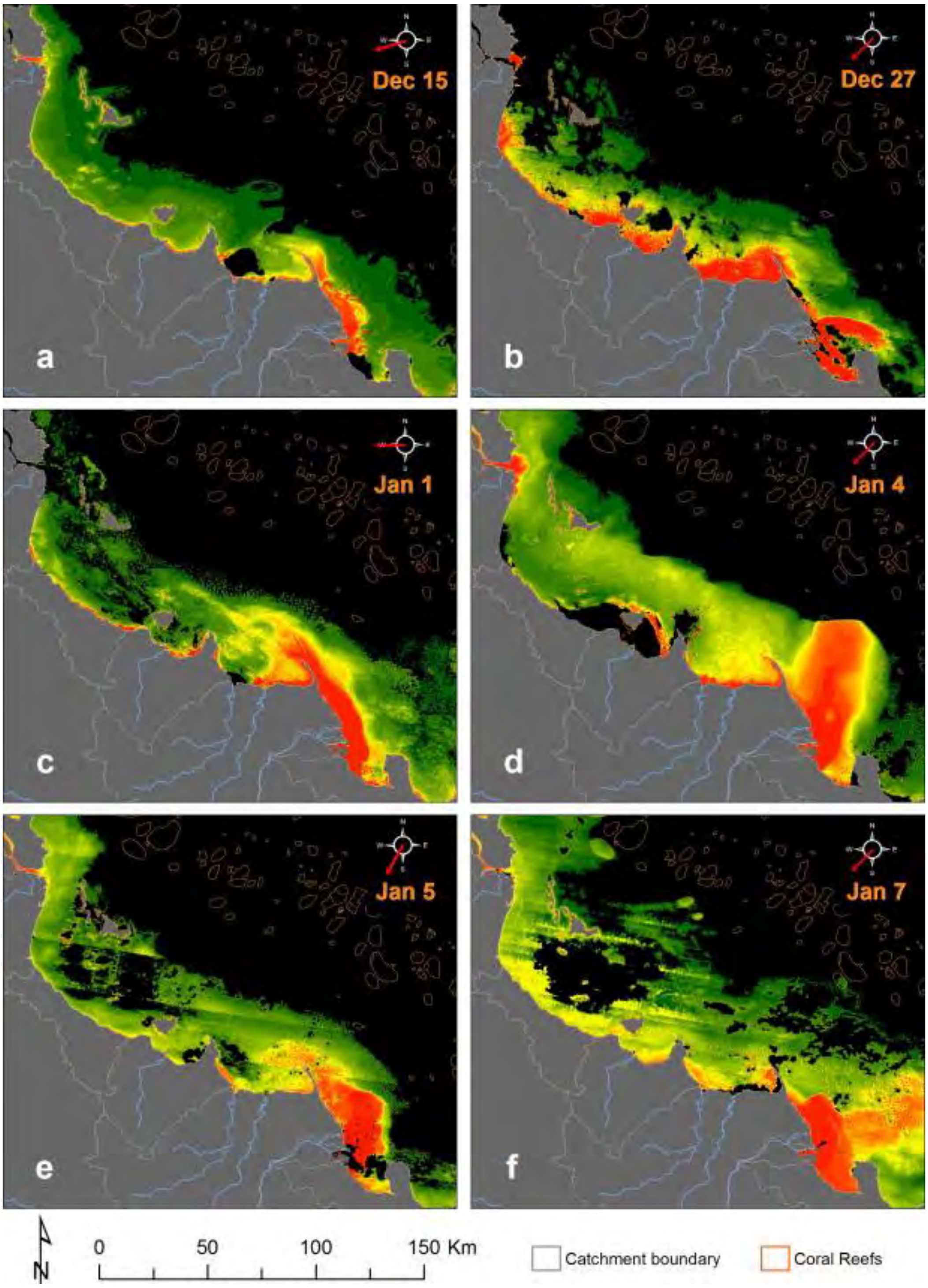
Appendix A TUFLOW FV Description

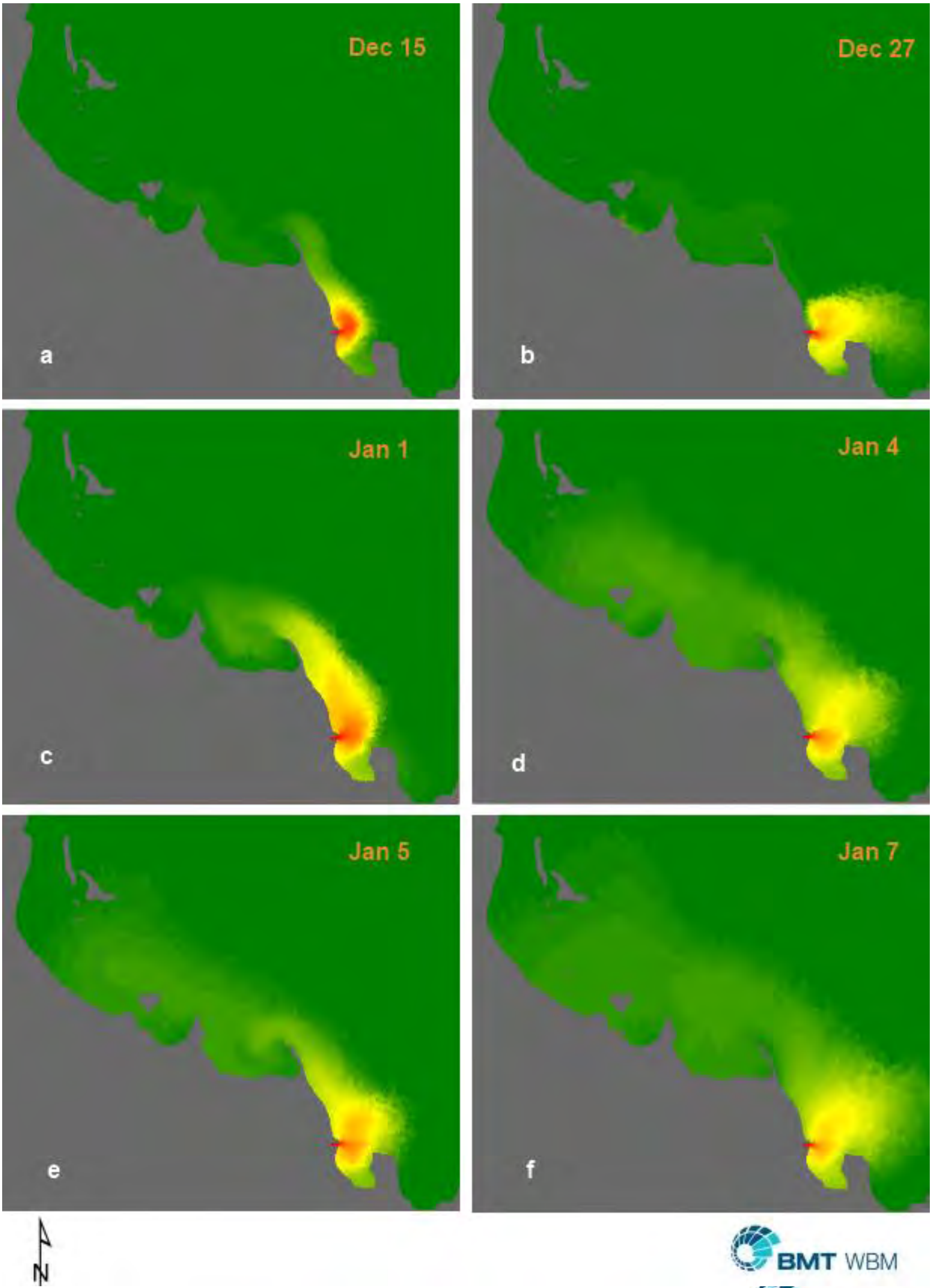
Appendix B Summer 2010/11 River Plumes

MODIS satellite images reproduced from Figure 3 of Bainbridge et al. (2012) show the evolution of the Burdekin River flood plume from the 15/12/10 to 07/01/11.



Model snapshots of surface salinity at equivalent times (showing the extent of the river plume) are provided on the following page for comparison purposes.

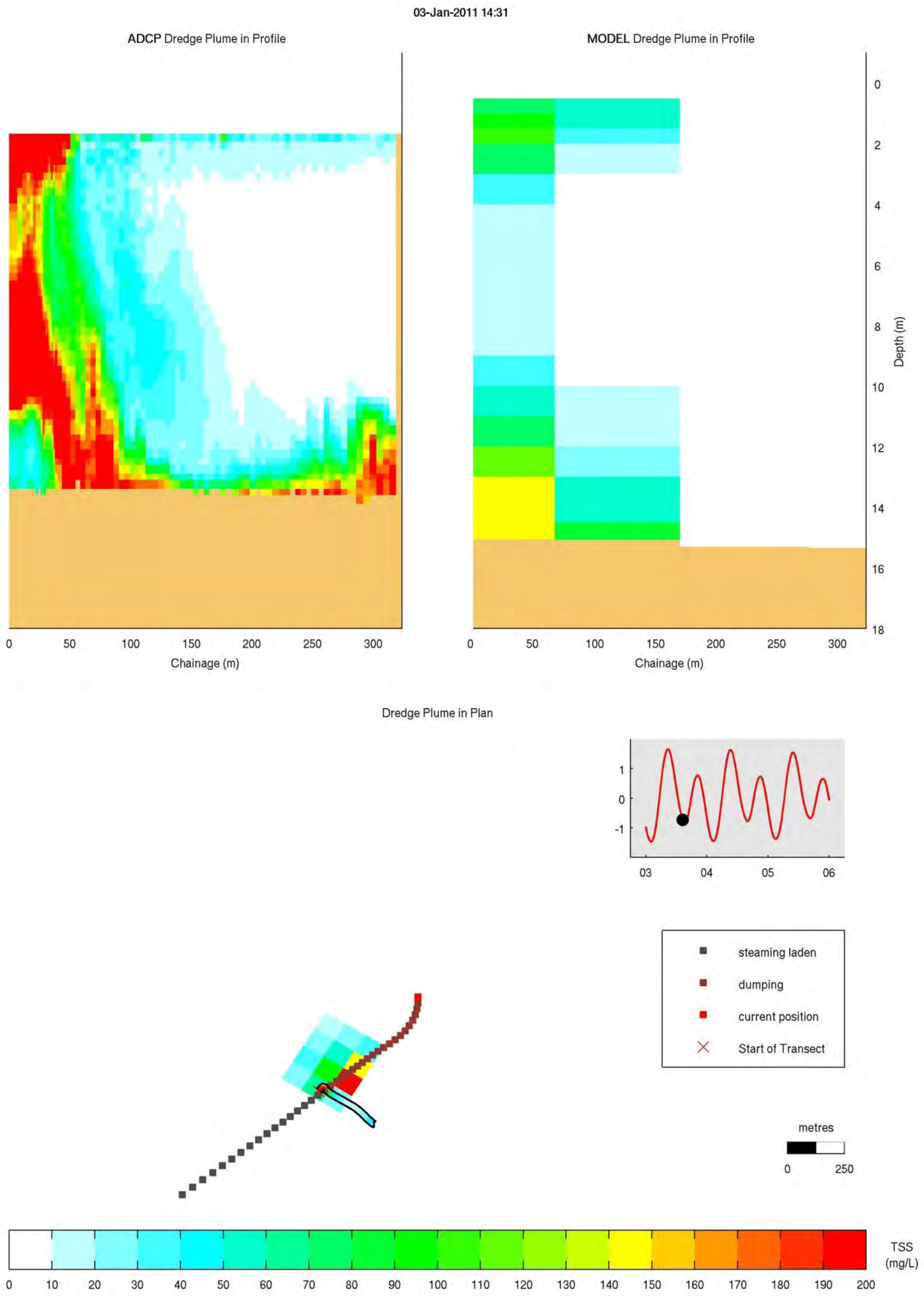
Summer 2010/11 River Plumes



BMT WBM

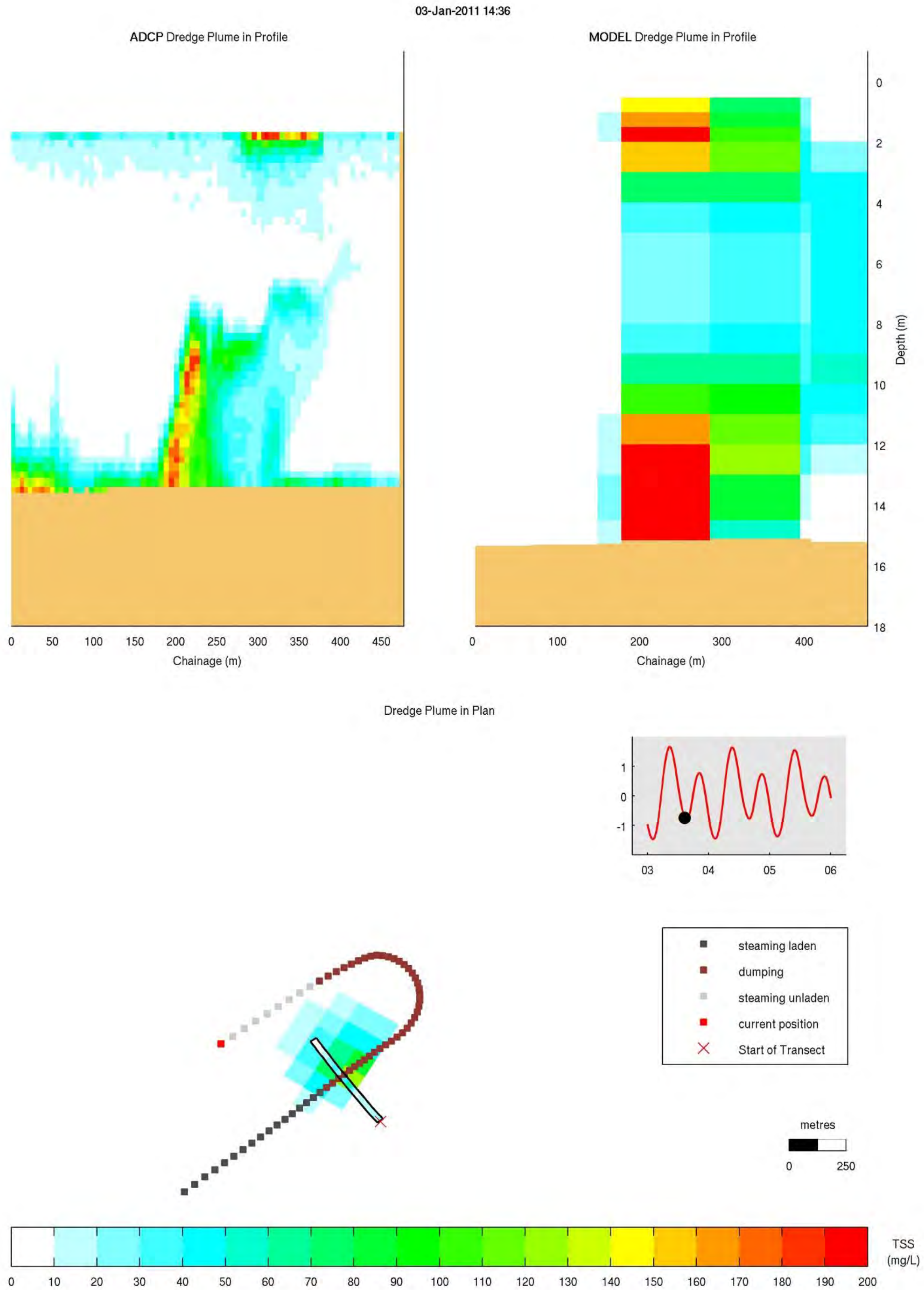
BMT WBM

Appendix C Dredge Plume Model Calibration Plots

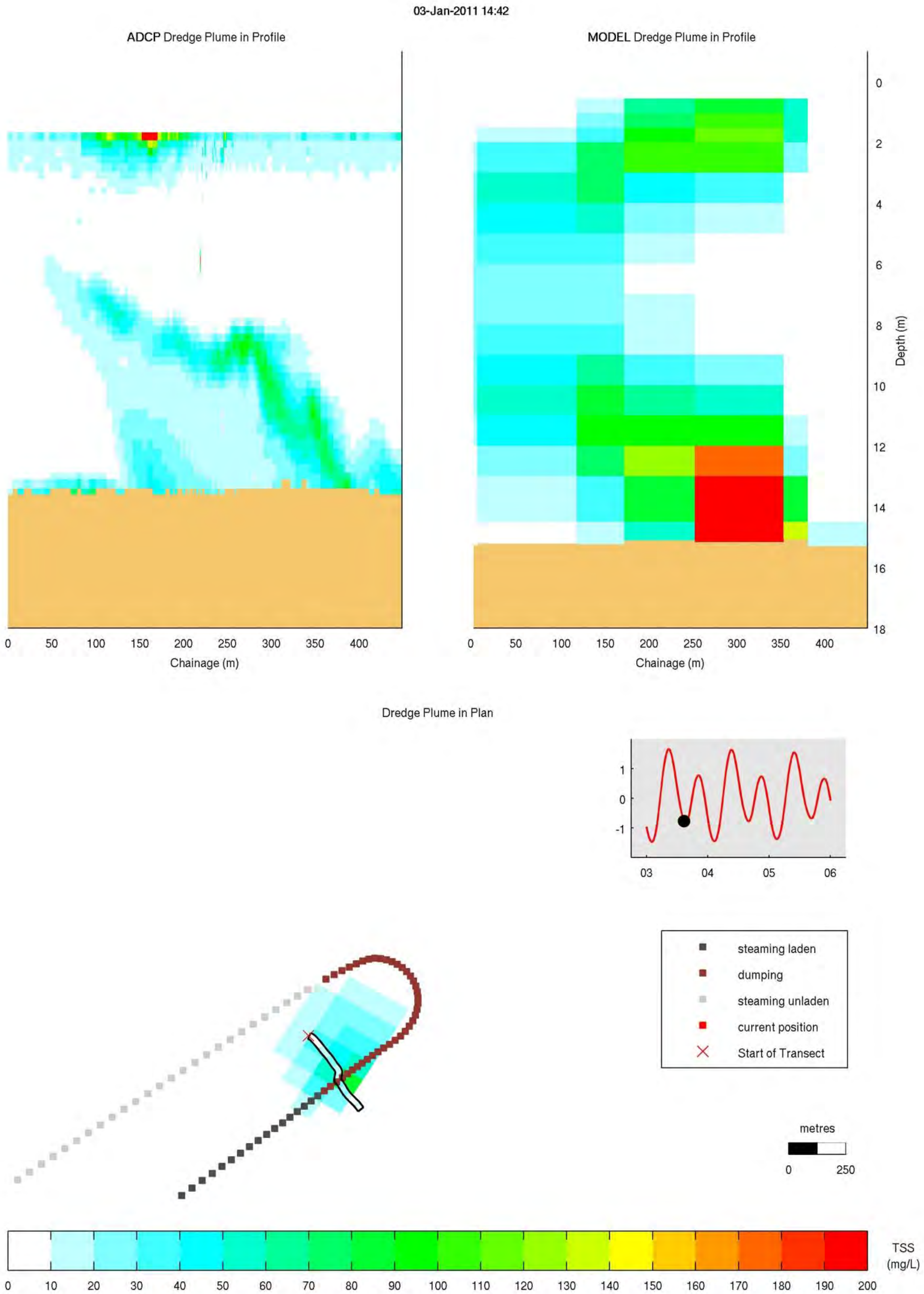


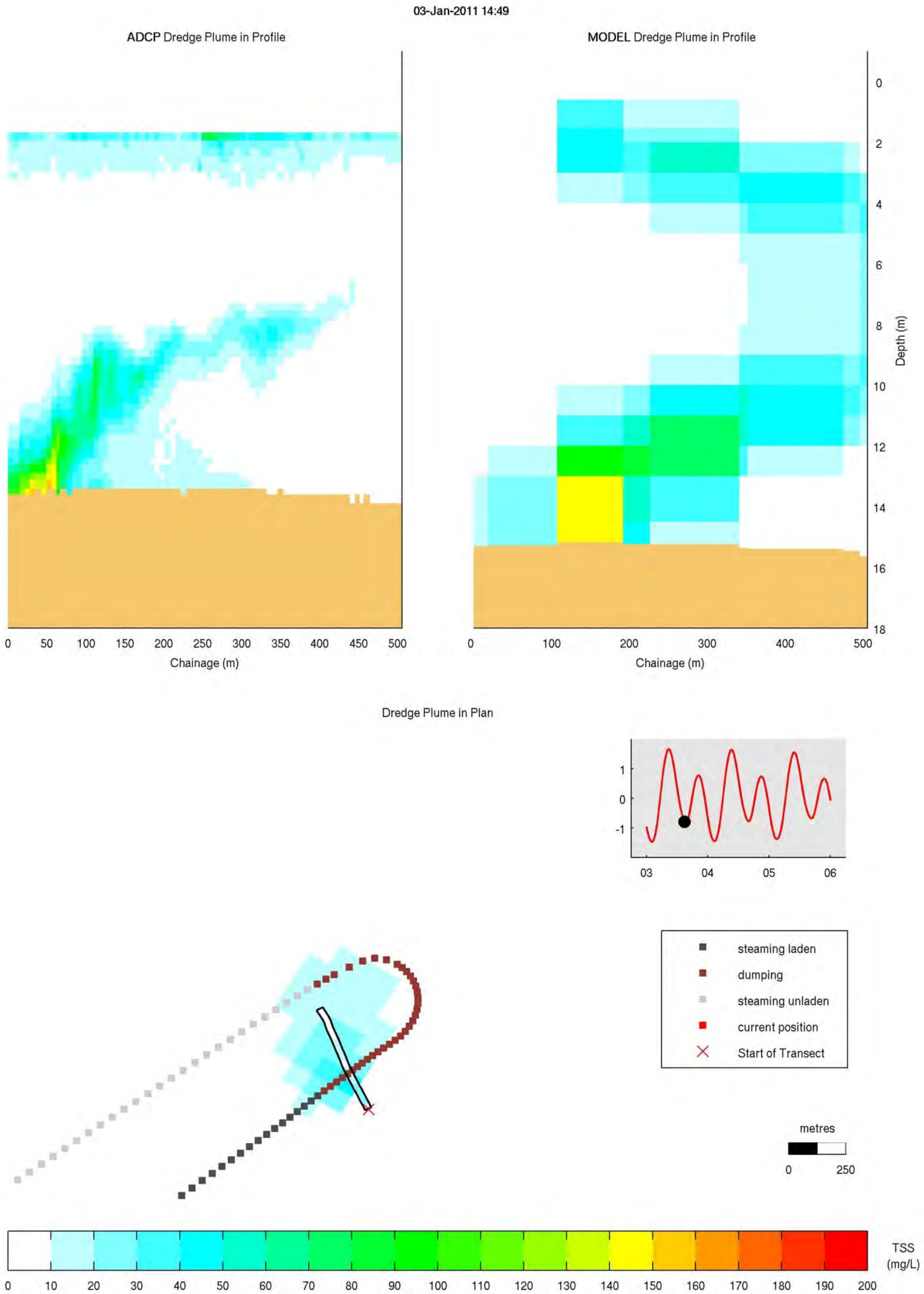
BMT WBM

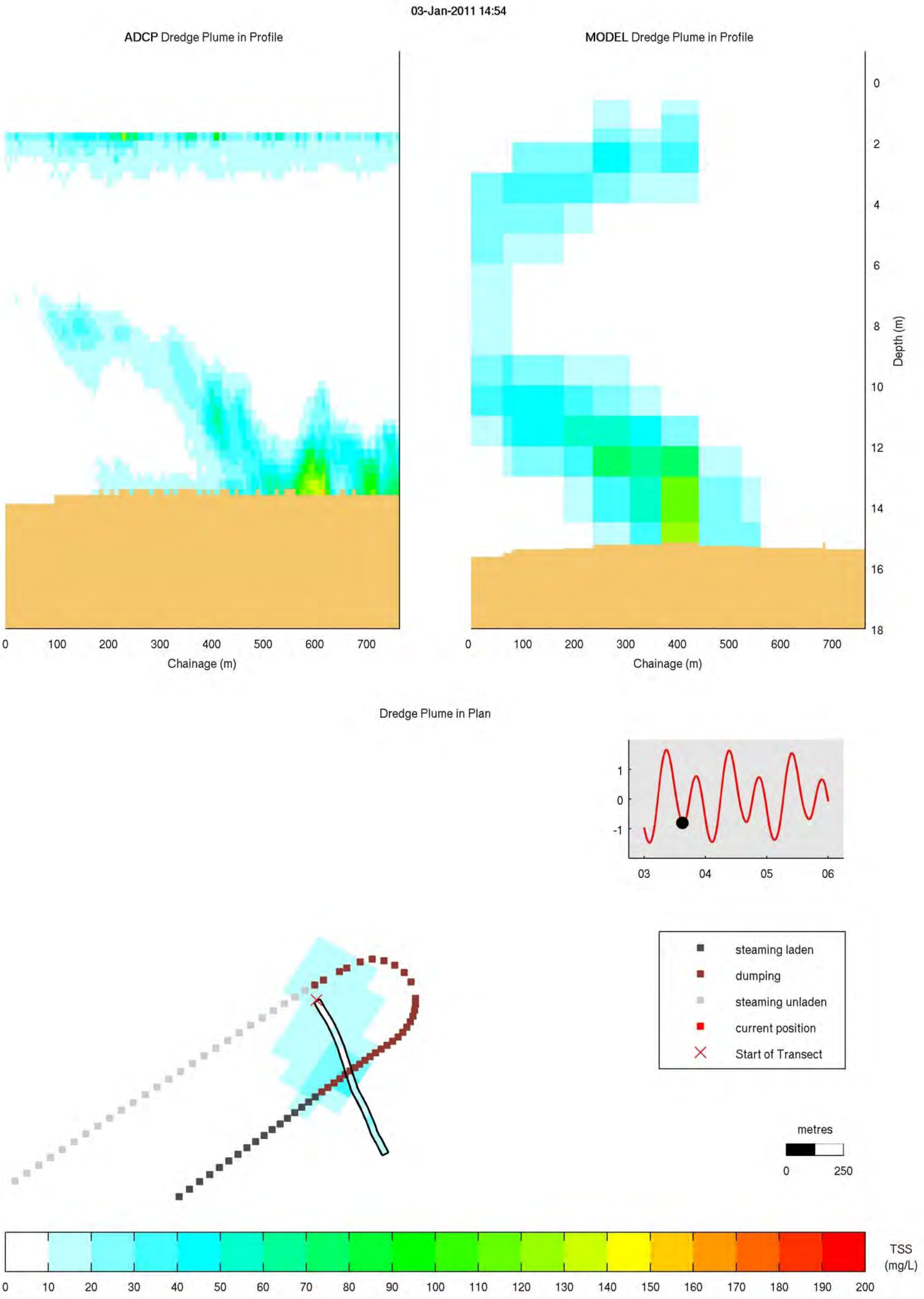
Dredge Plume Model Calibration Plots



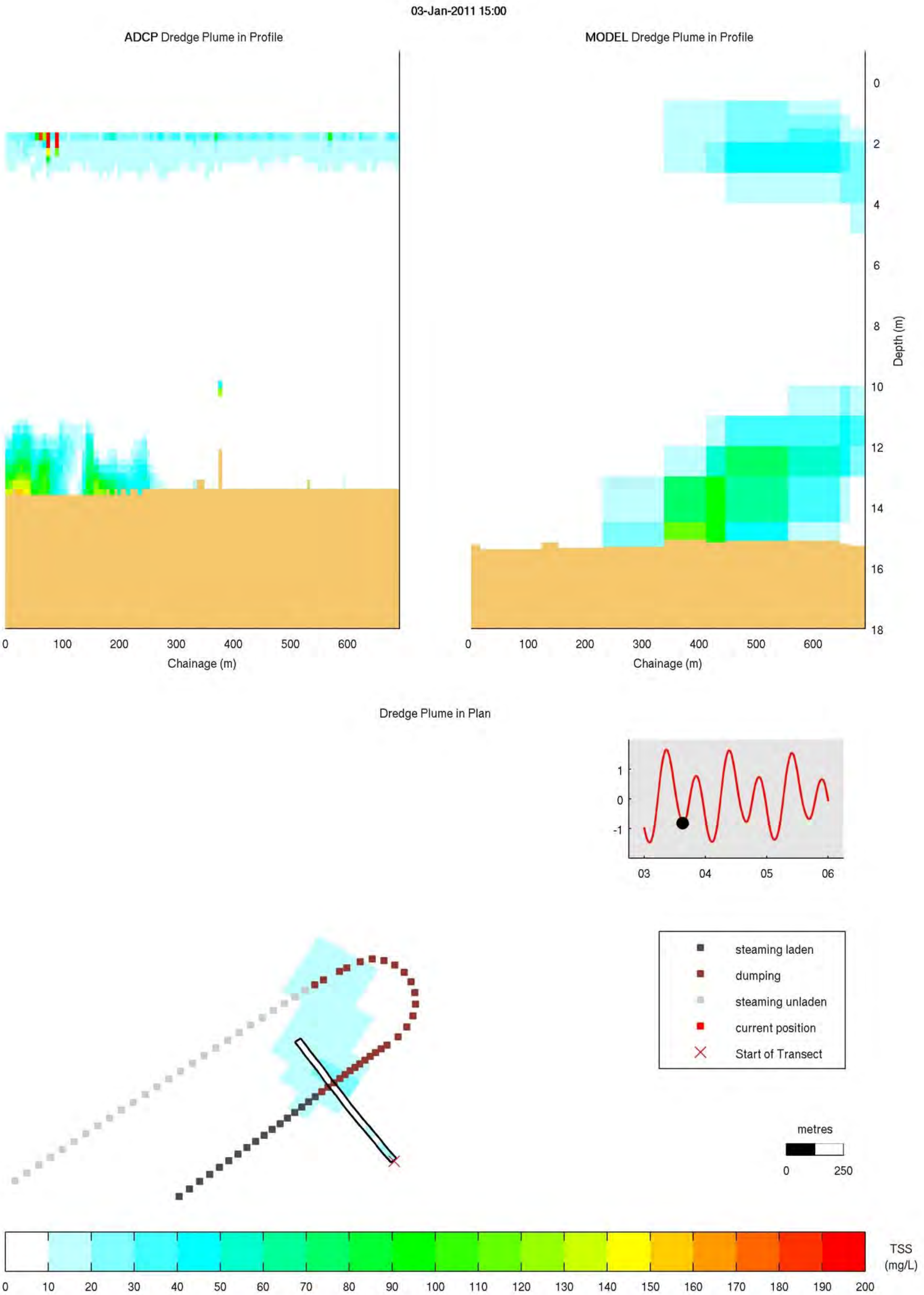
Dredge Plume Model Calibration Plots

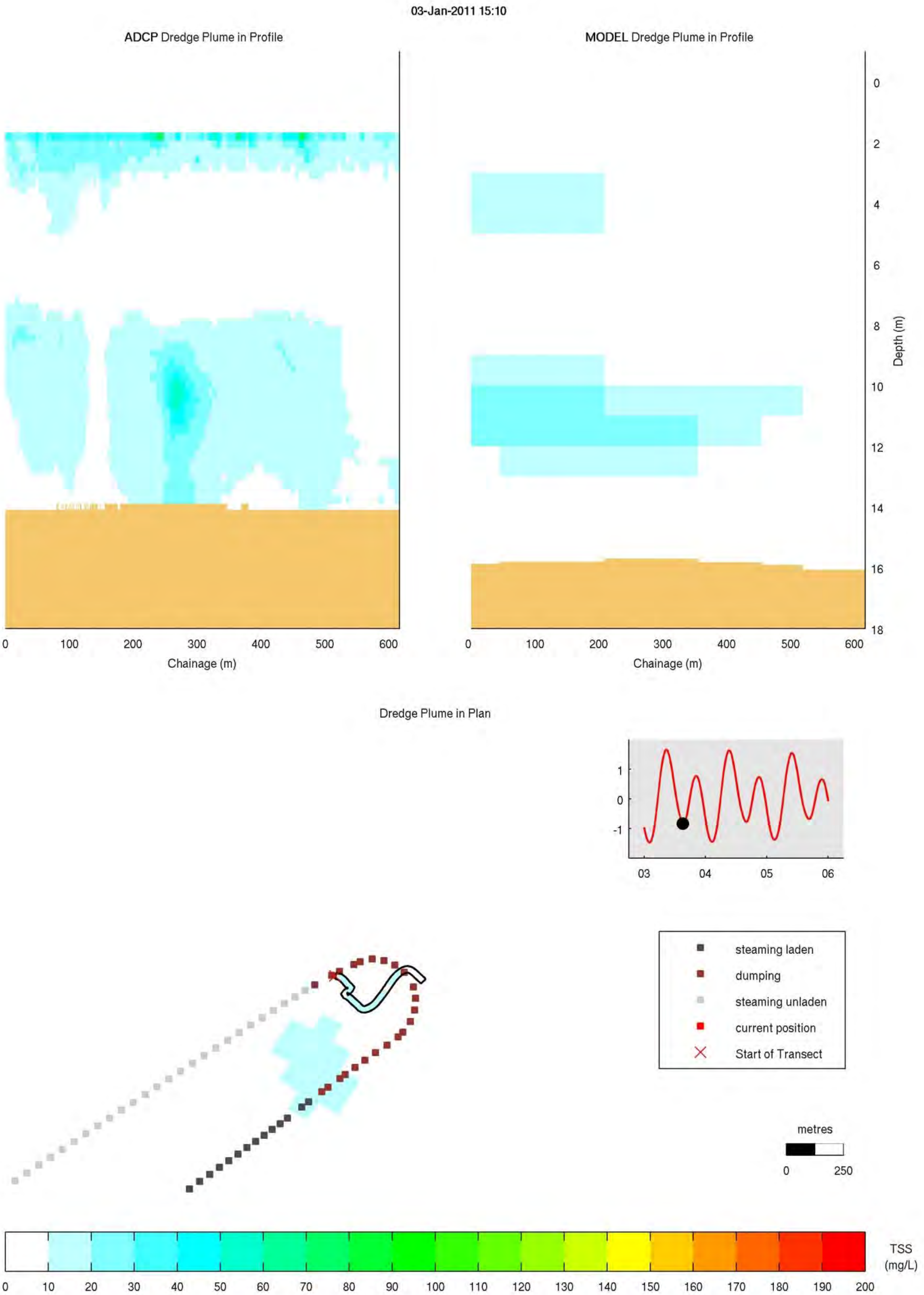



03-Jan-2011 14:49
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)


03-Jan-2011 14:54
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

Dredge Plume Model Calibration Plots

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ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
Chainage (m)
0
100
200
300
400
500
600
Dredge Plume in Plan
1
0
-1
03
04
05
06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)
0
10
20
30
40
50
60
70
80
90
100
110
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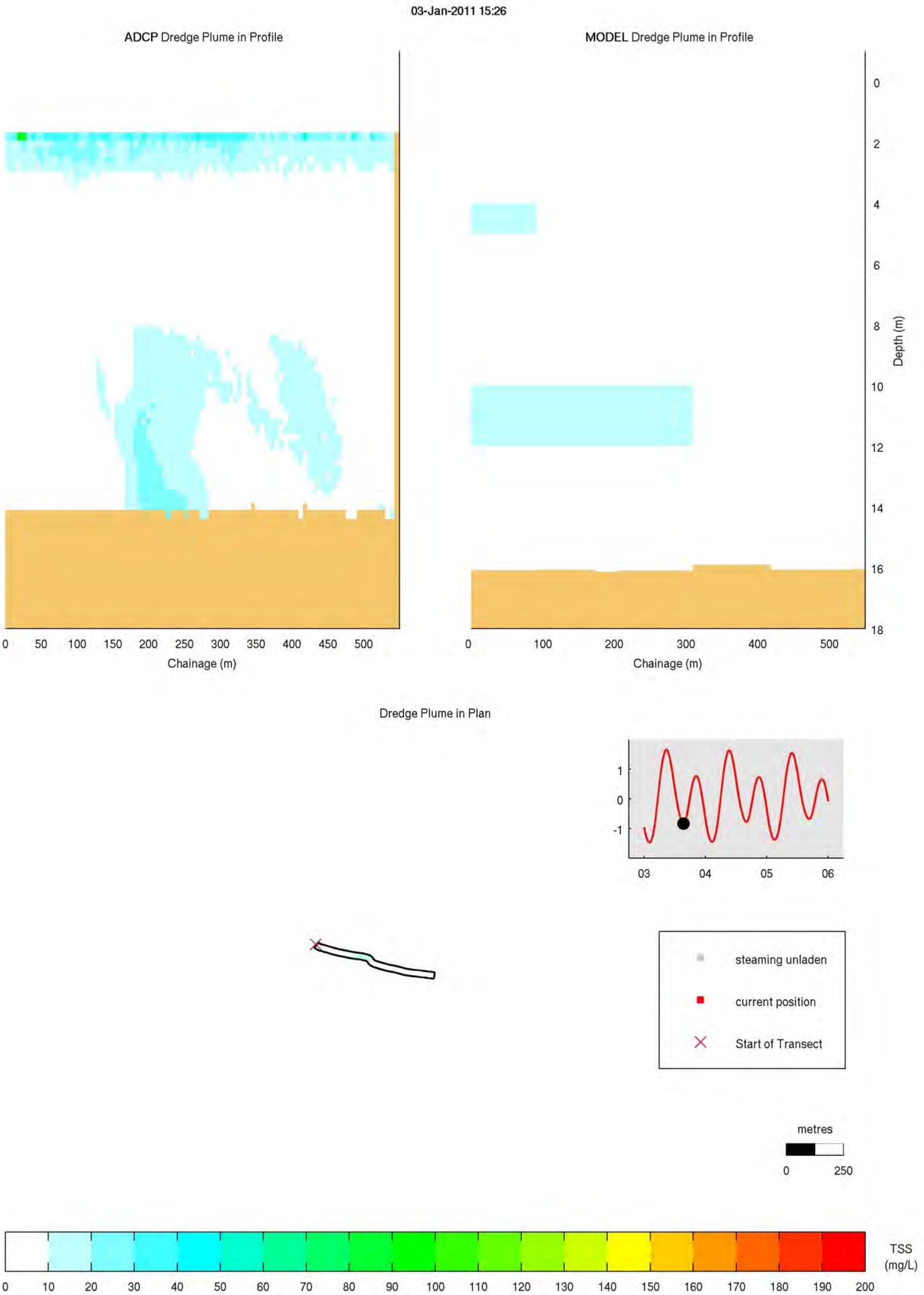
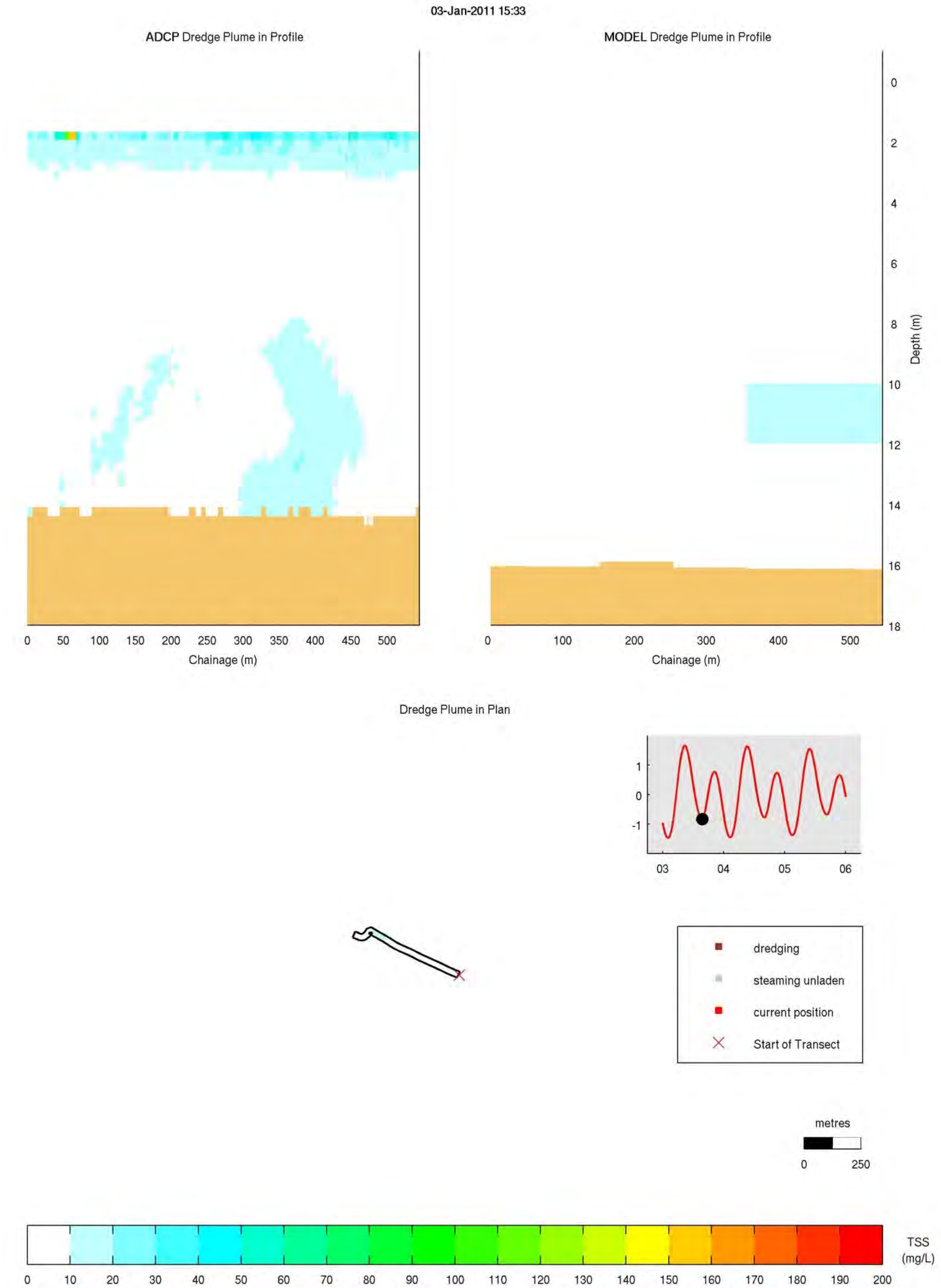
200

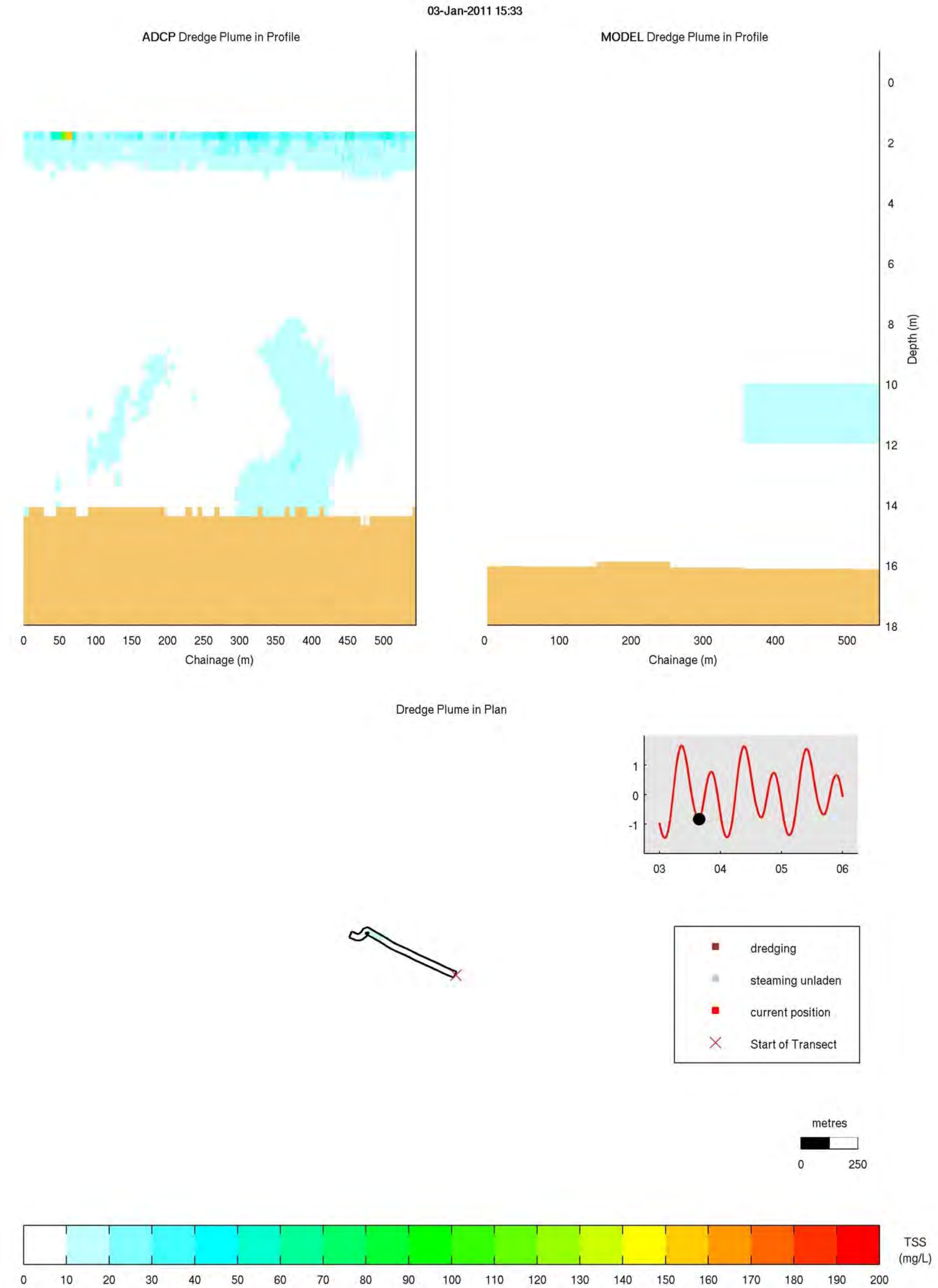
Dredge Plume Model Calibration Plots



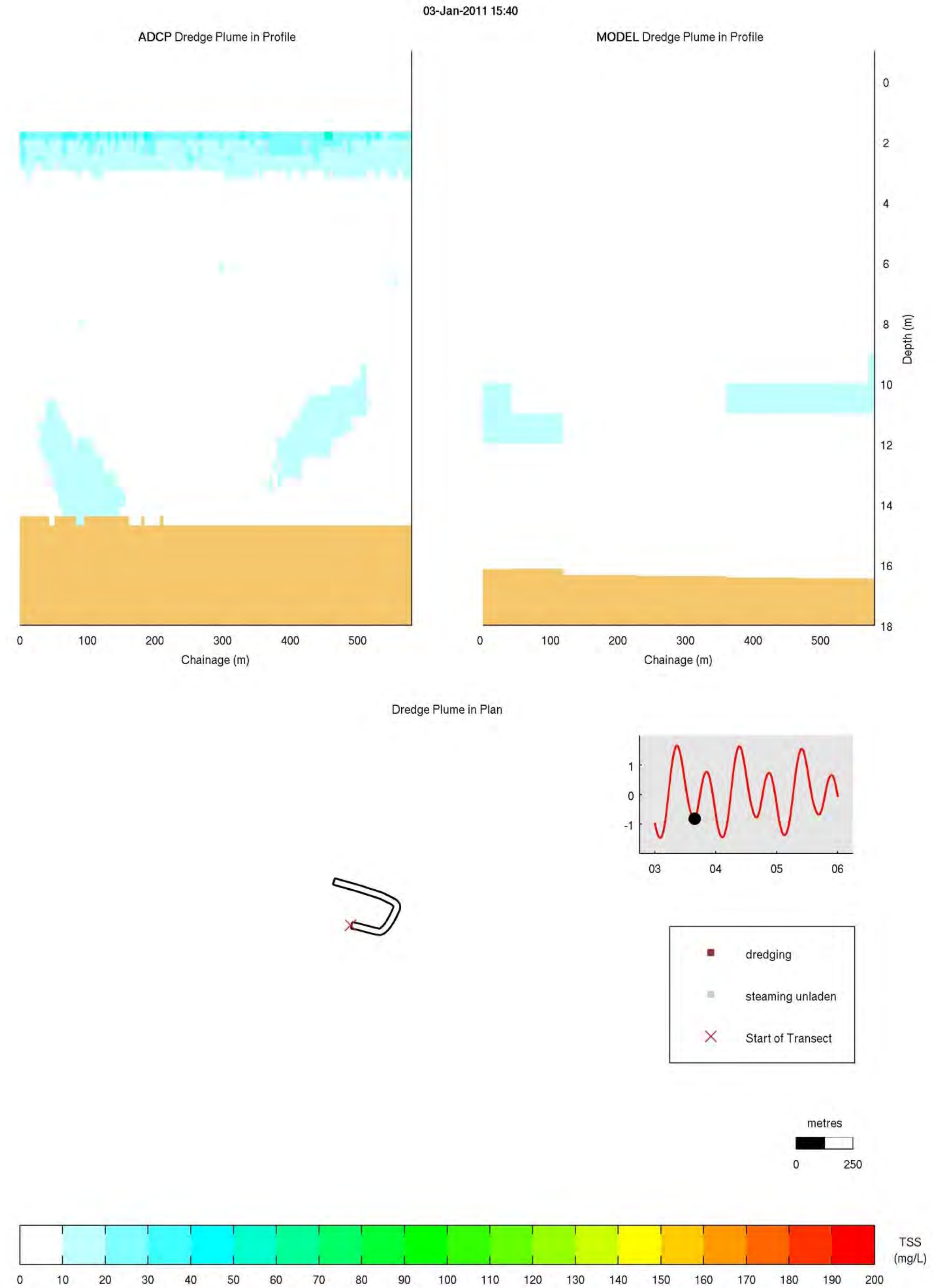
Dredge Plume Model Calibration Plots

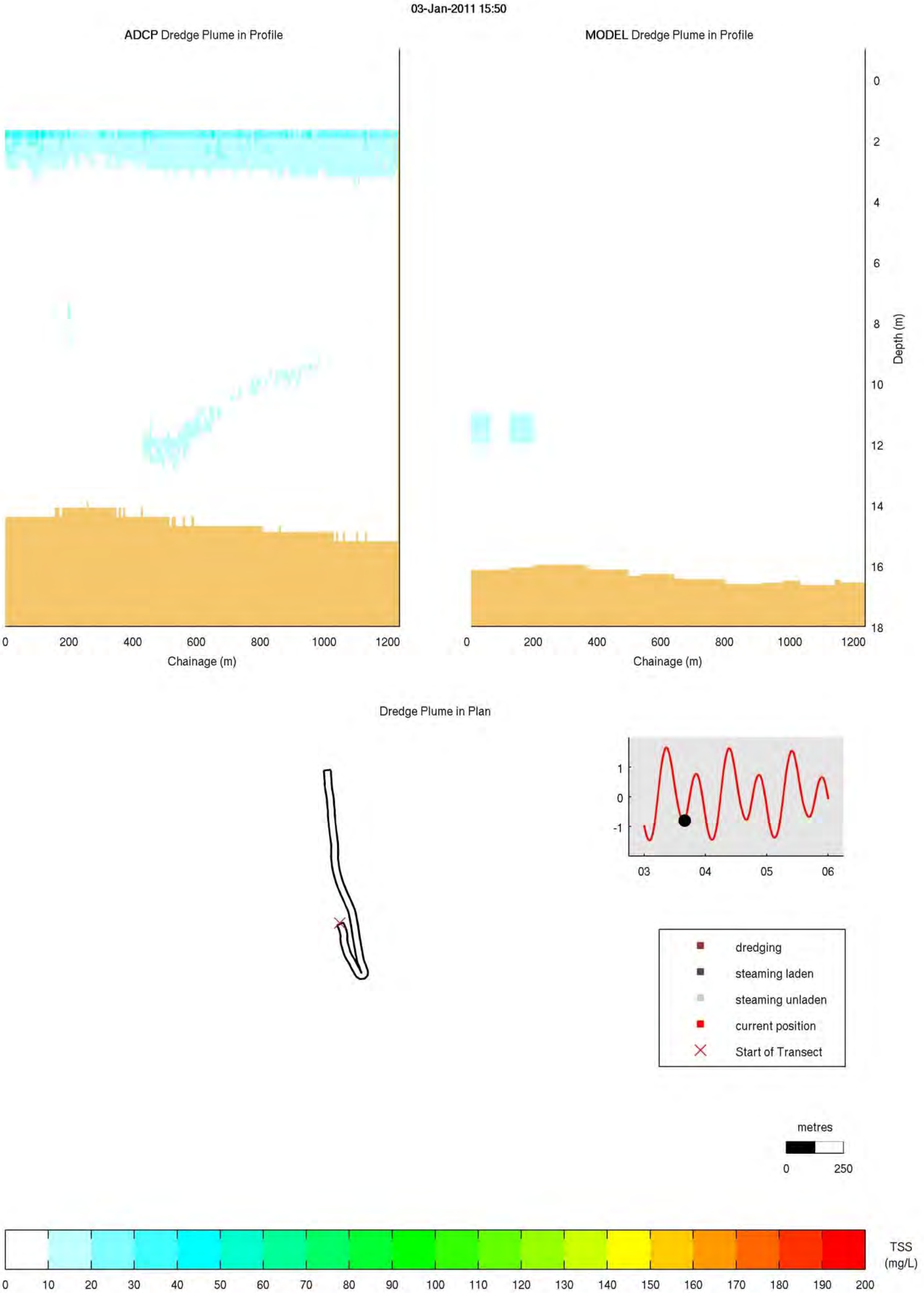


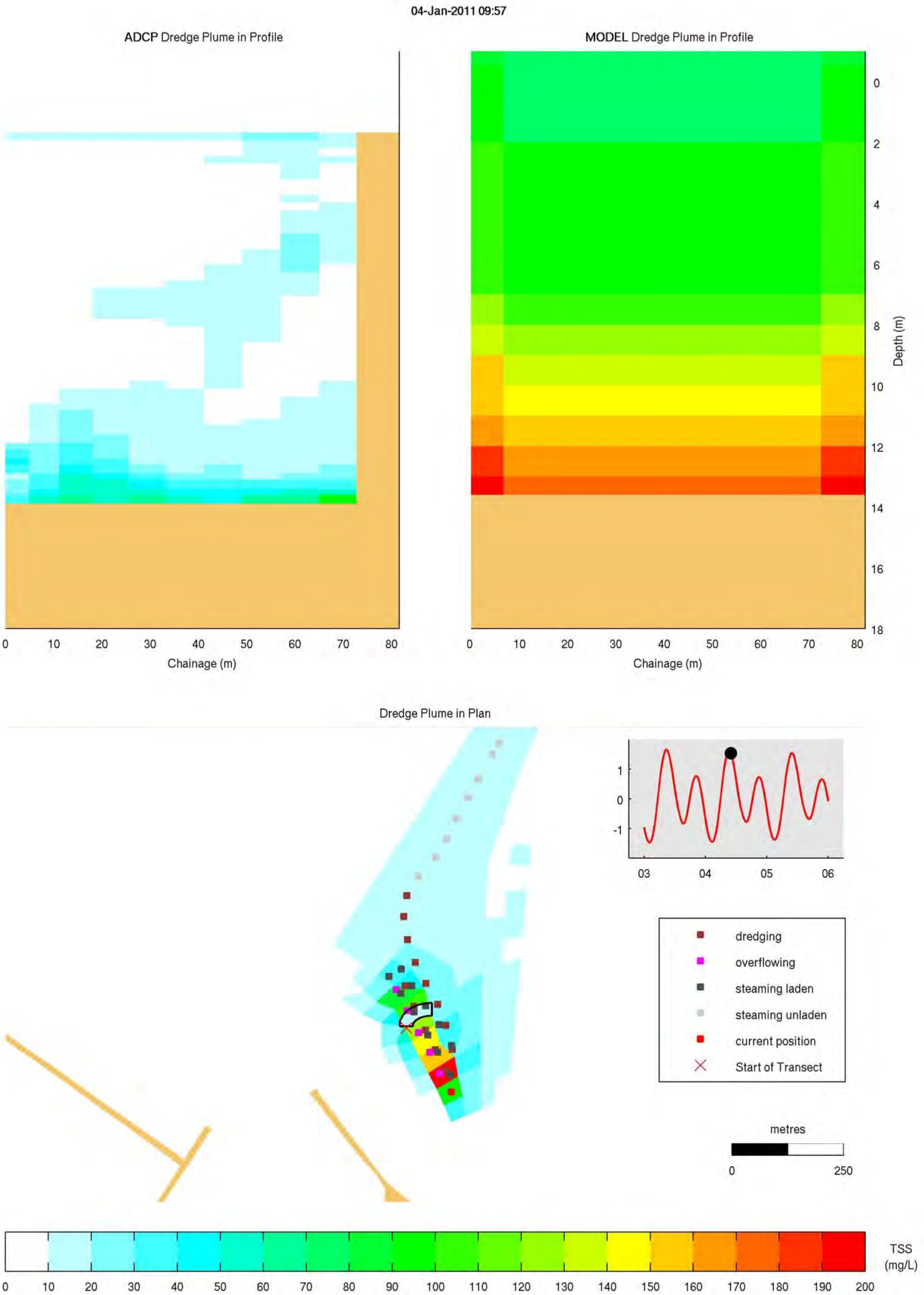
Dredge Plume Model Calibration Plots



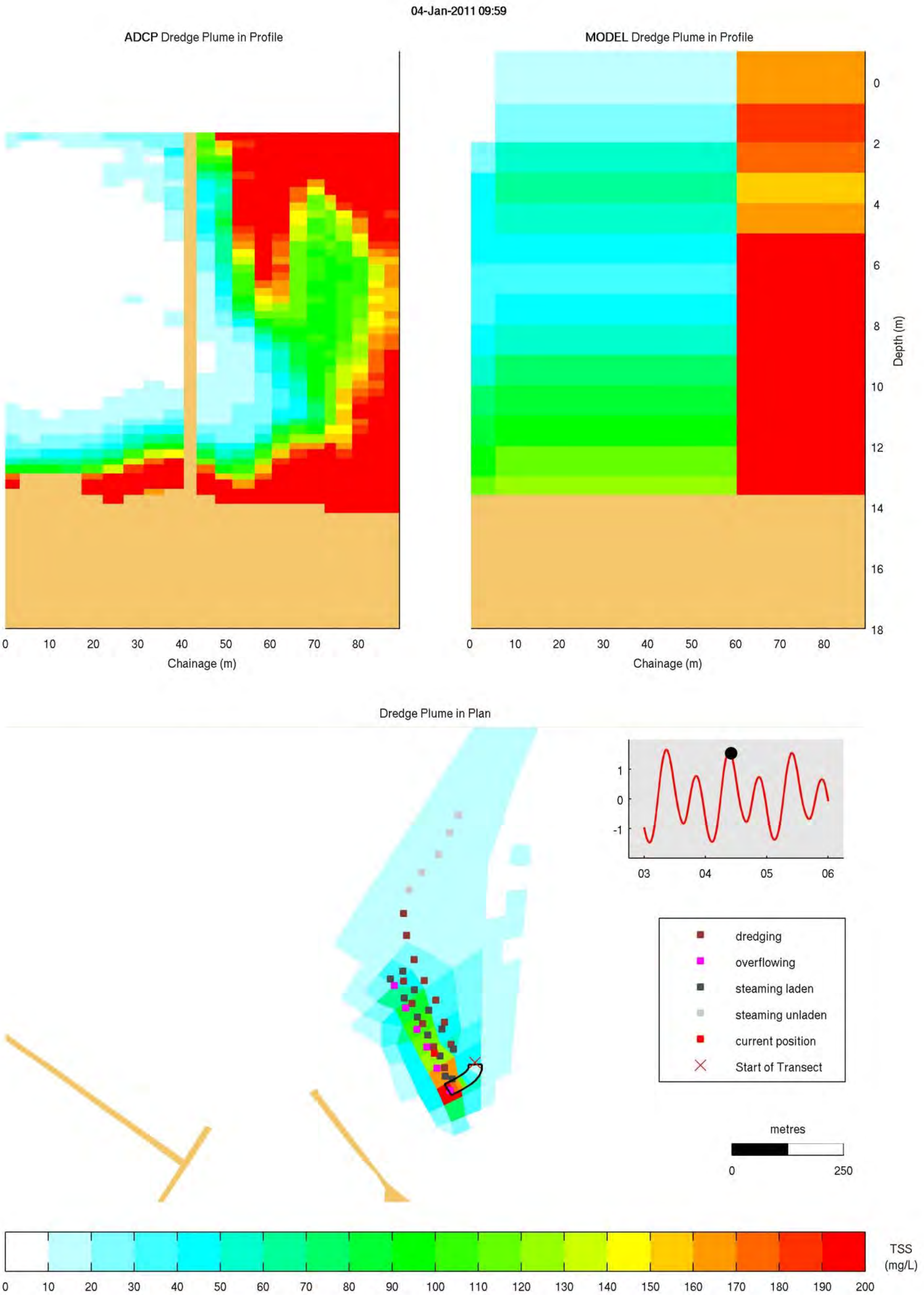
Dredge Plume Model Calibration Plots



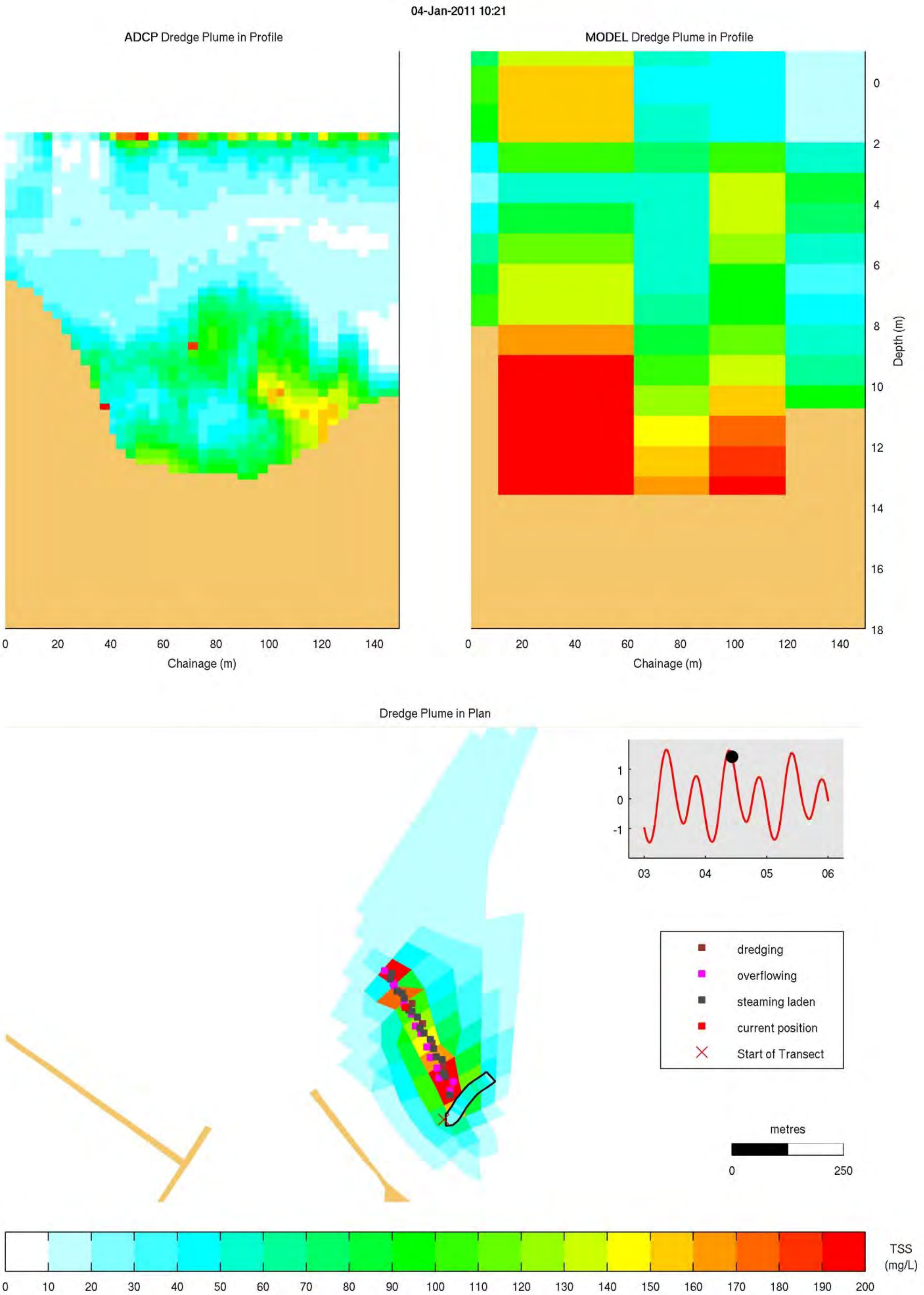

03-Jan-2011 15:50
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
03
04
05
06
dredging
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)


04-Jan-2011 09:57
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
Chainage (m)
0 10 20 30 40 50 60 70 80
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0 250
TSS
(mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

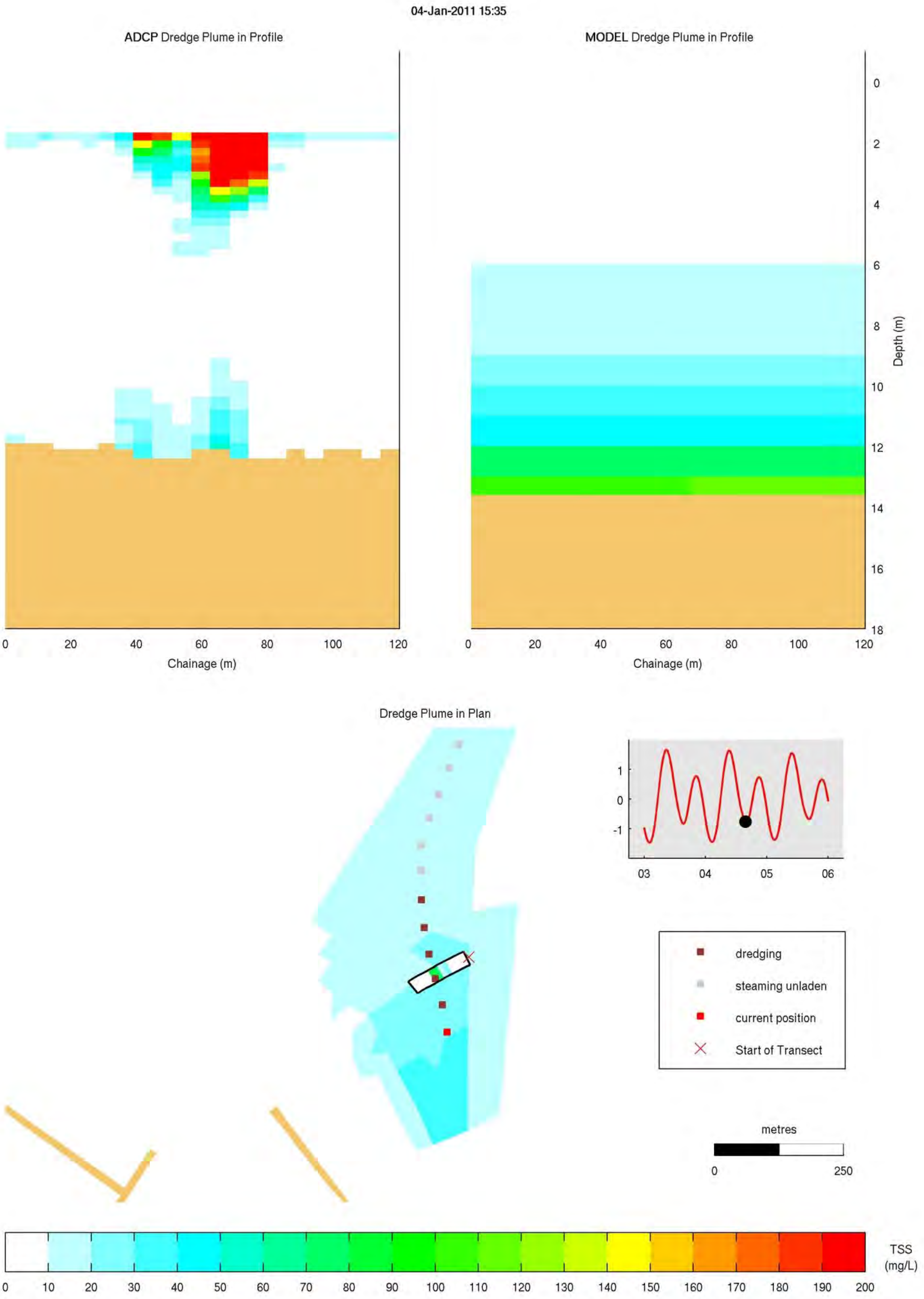
Dredge Plume Model Calibration Plots

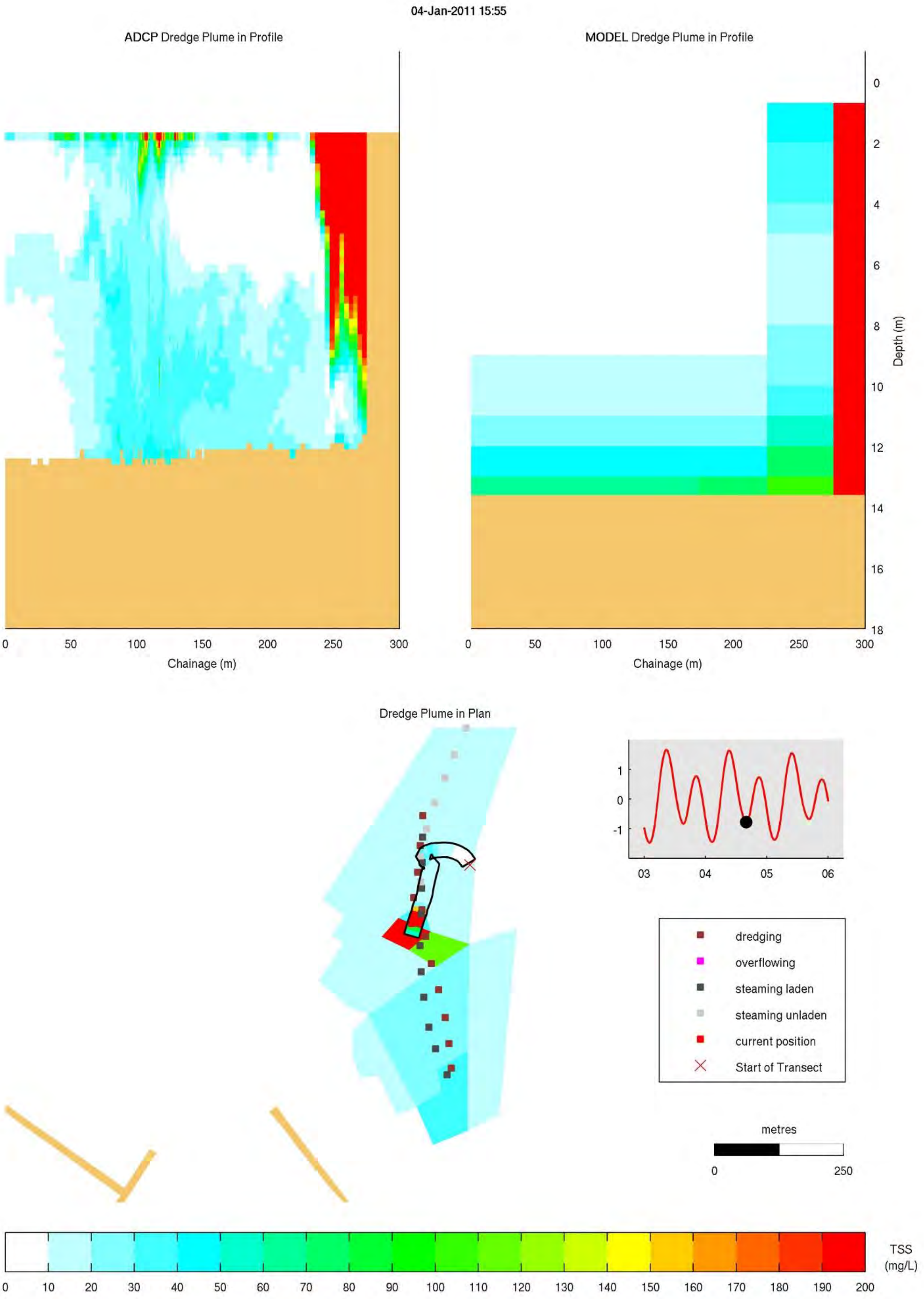


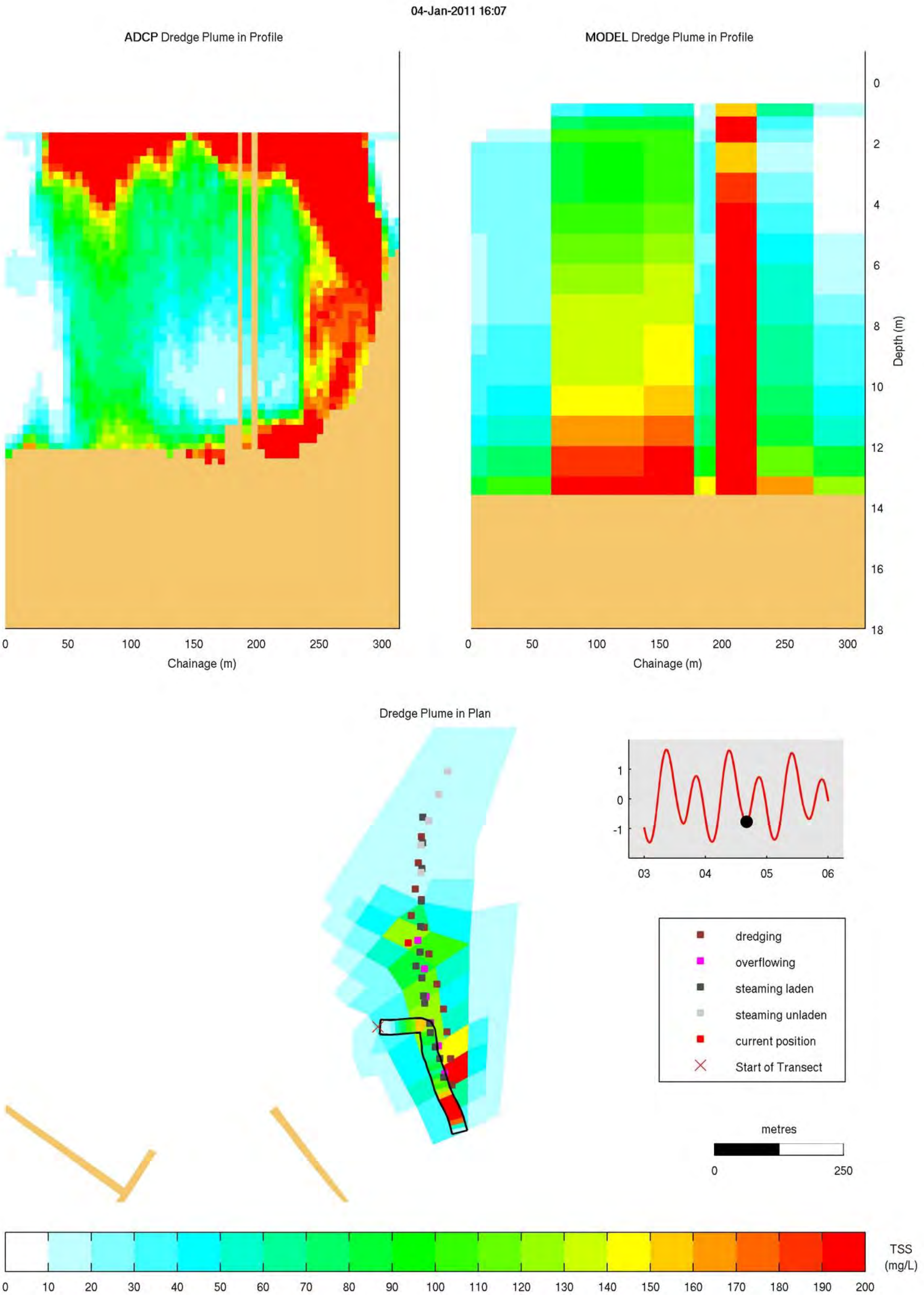
BMT WBM


04-Jan-2011 10:21
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
0
2
4
6
8
10
12
14
16
18
0 20 40 60 80 100 120 140
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0 250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

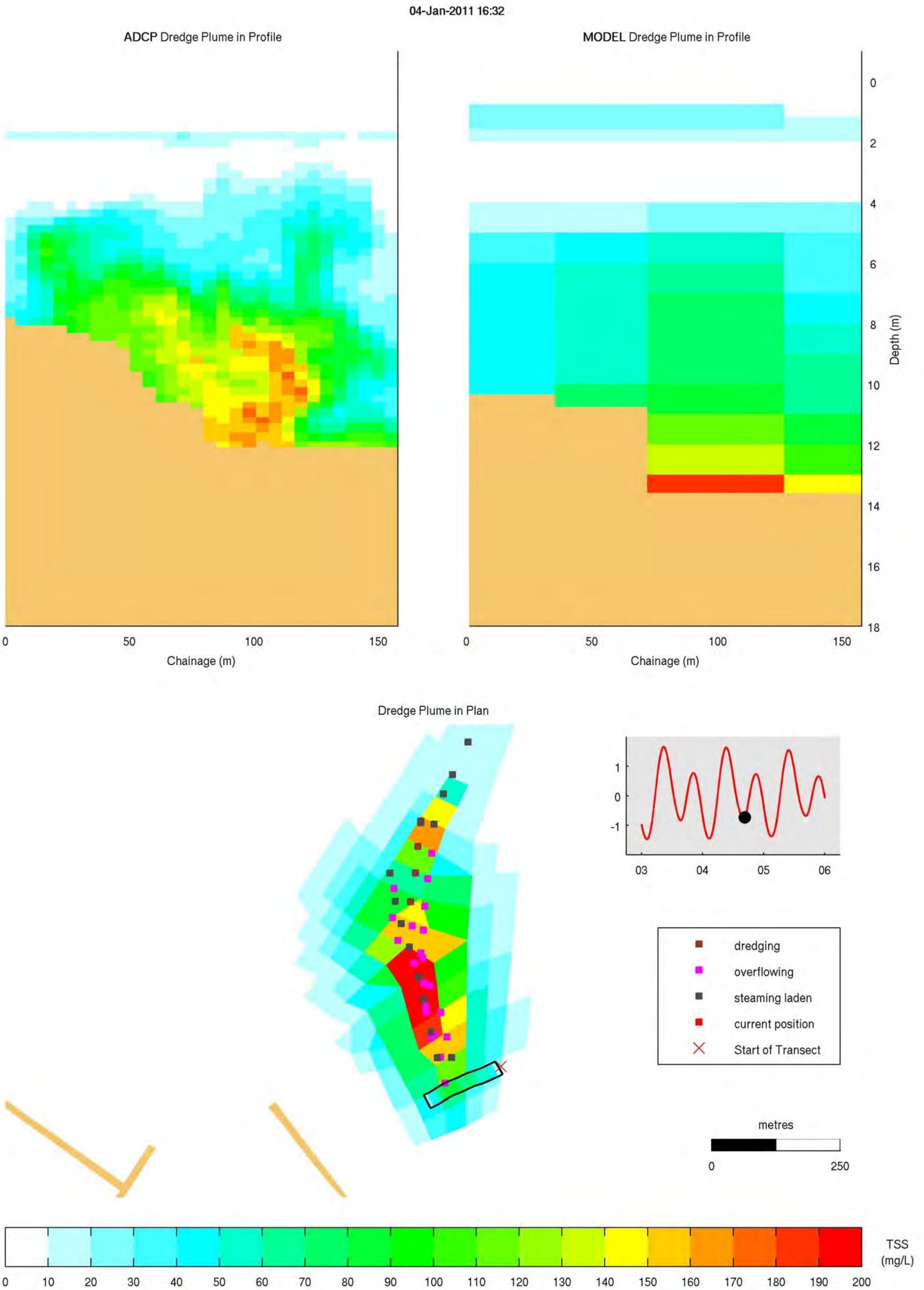
Dredge Plume Model Calibration Plots



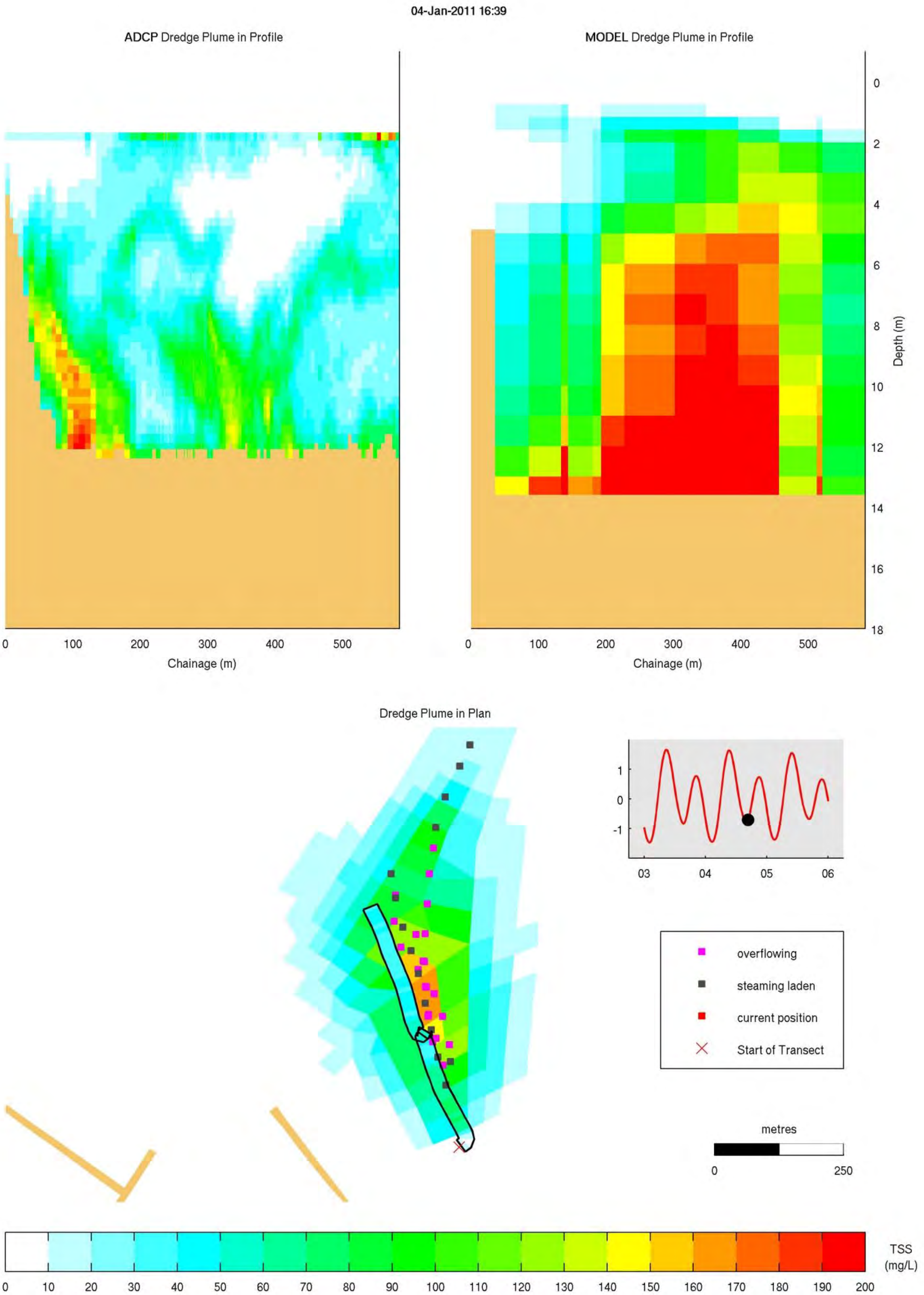

04-Jan-2011 15:55
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)


04-Jan-2011 16:07
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

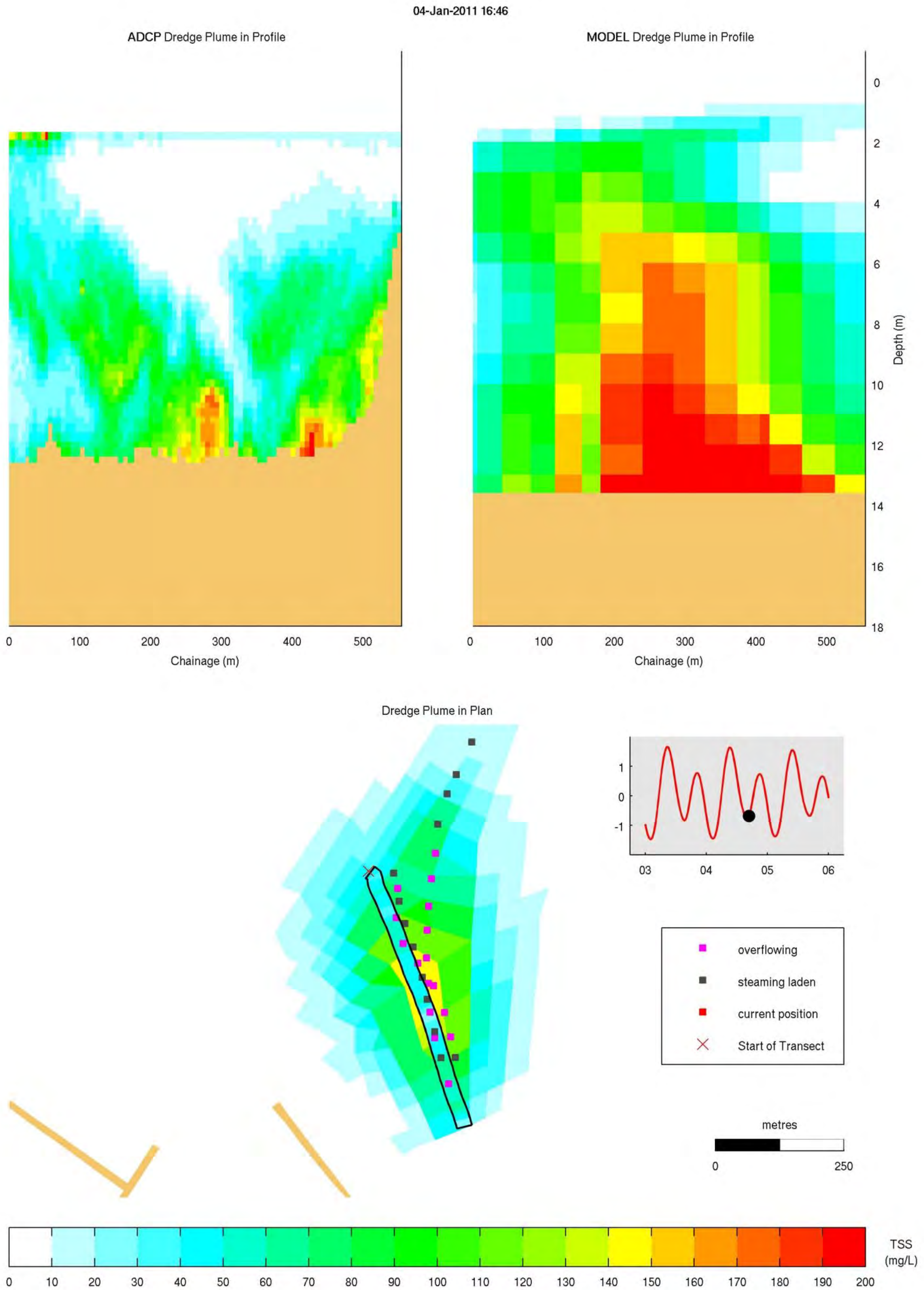
Dredge Plume Model Calibration Plots

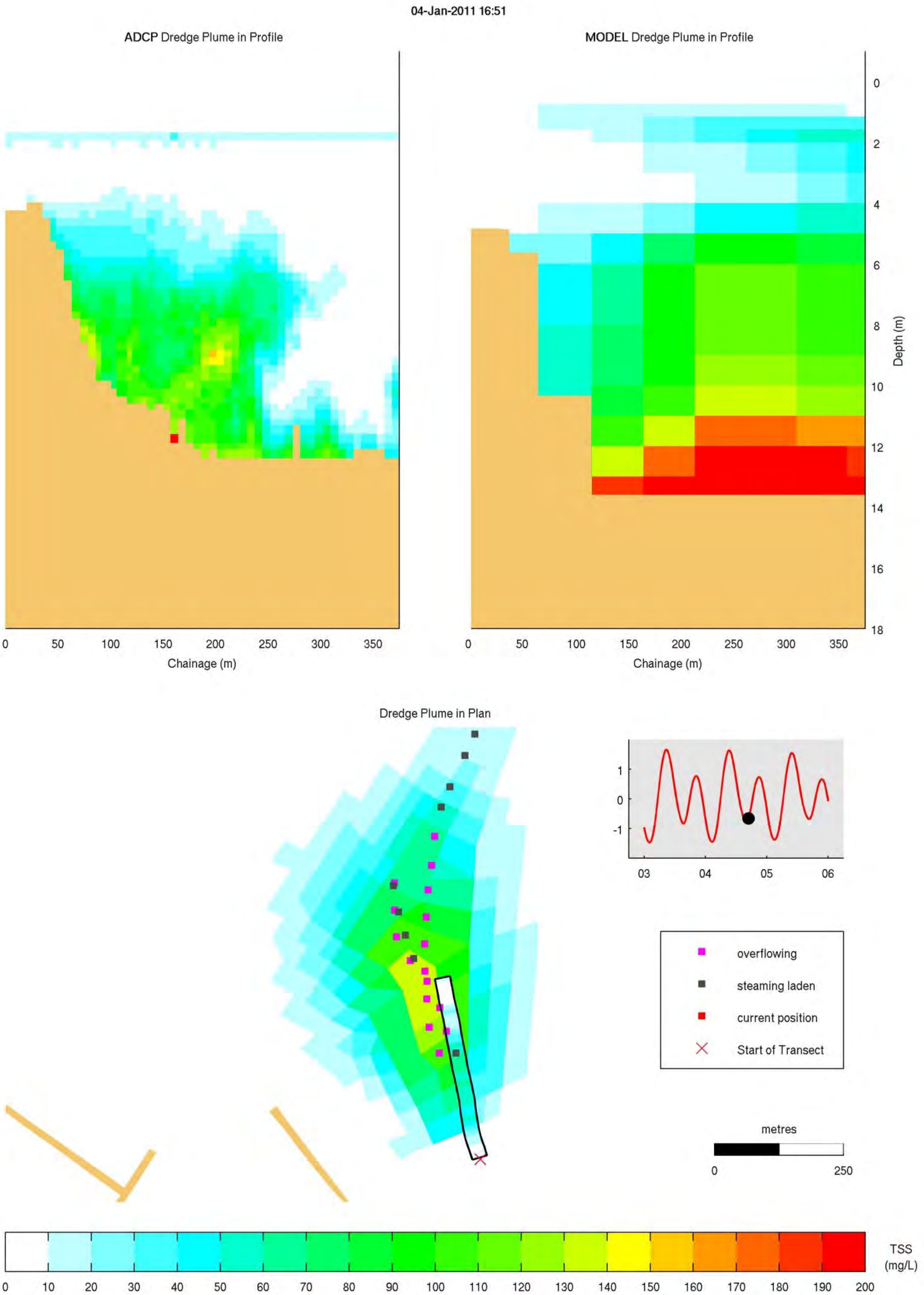


Dredge Plume Model Calibration Plots

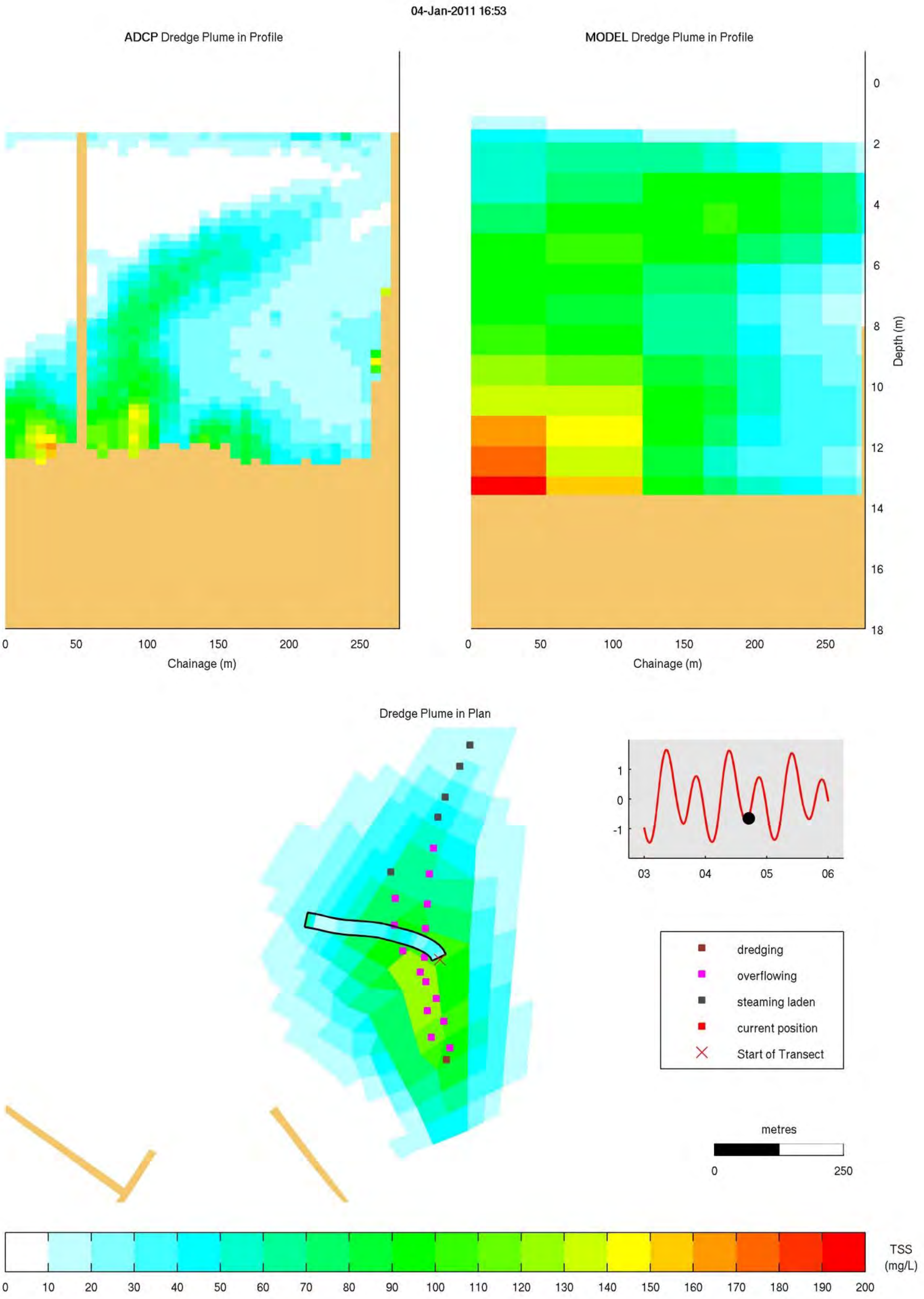


Dredge Plume Model Calibration Plots



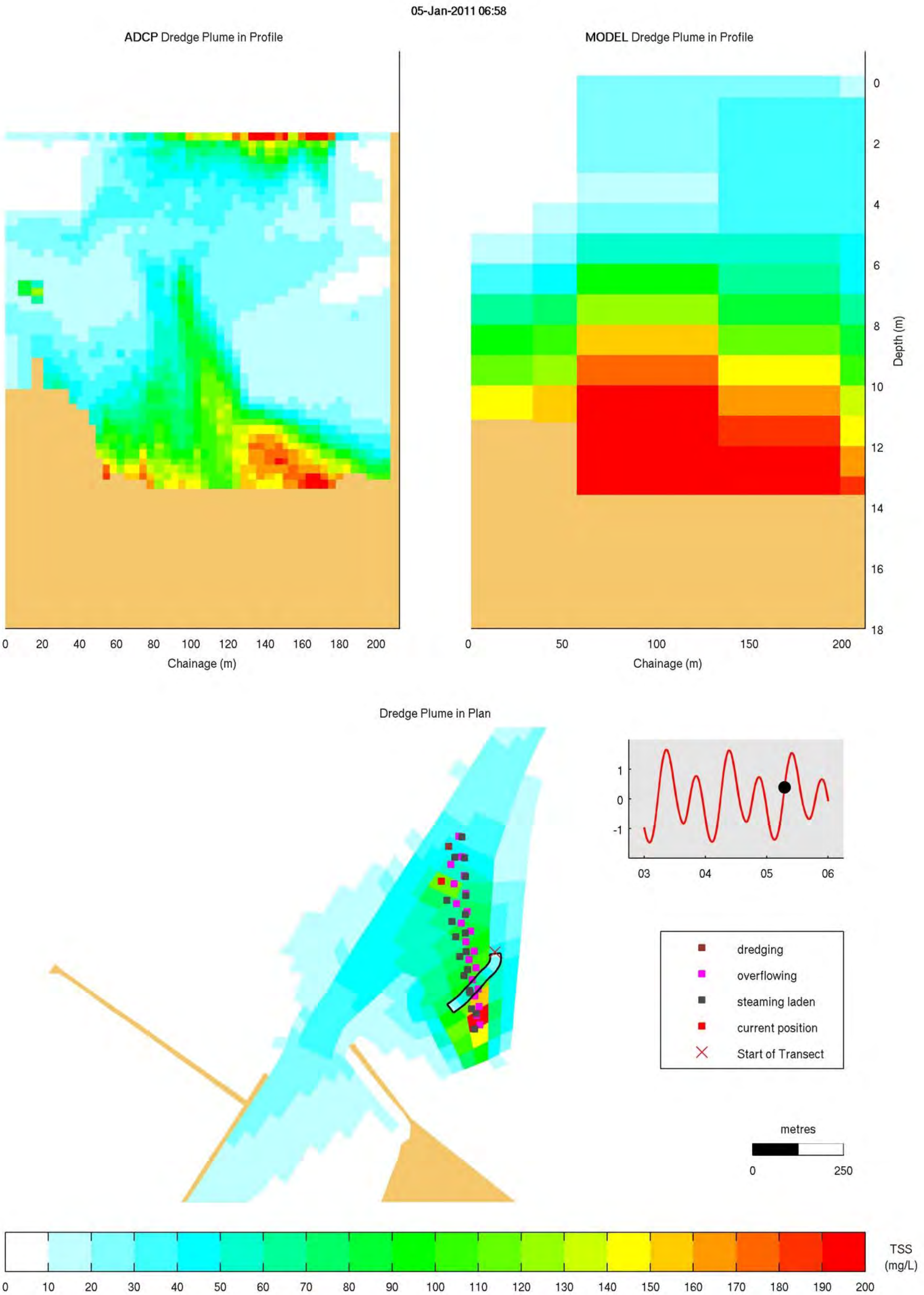

04-Jan-2011 16:51
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
0
50
100
150
200
250
300
350
2
4
6
8
10
12
14
16
18
Dredge Plume in Plan
1
0
-1
03
04
05
06
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)
10
20
30
40
60
70
80
90
110
120
130
140
160
170
180
190

Dredge Plume Model Calibration Plots

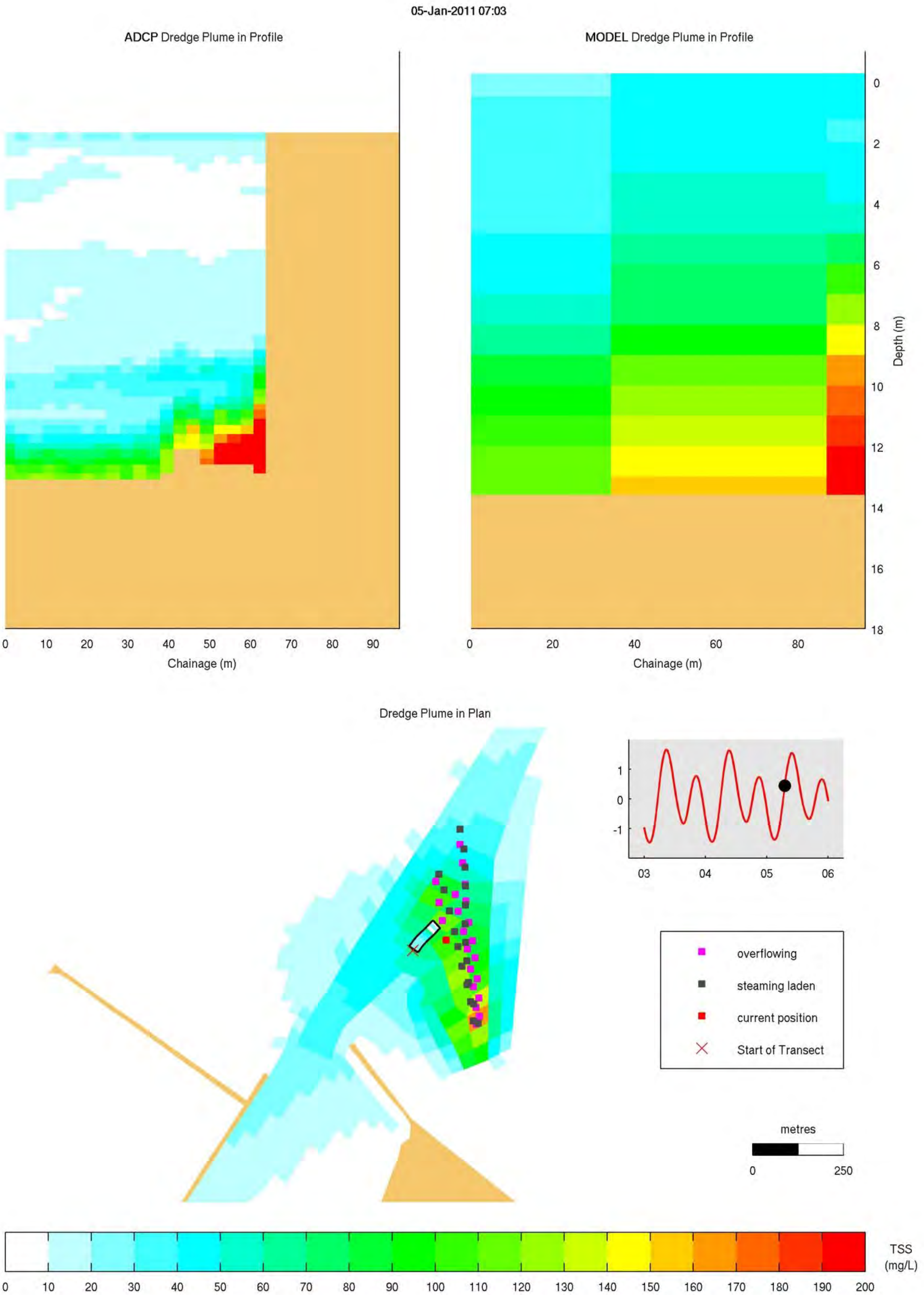


BMT WBM

Dredge Plume Model Calibration Plots

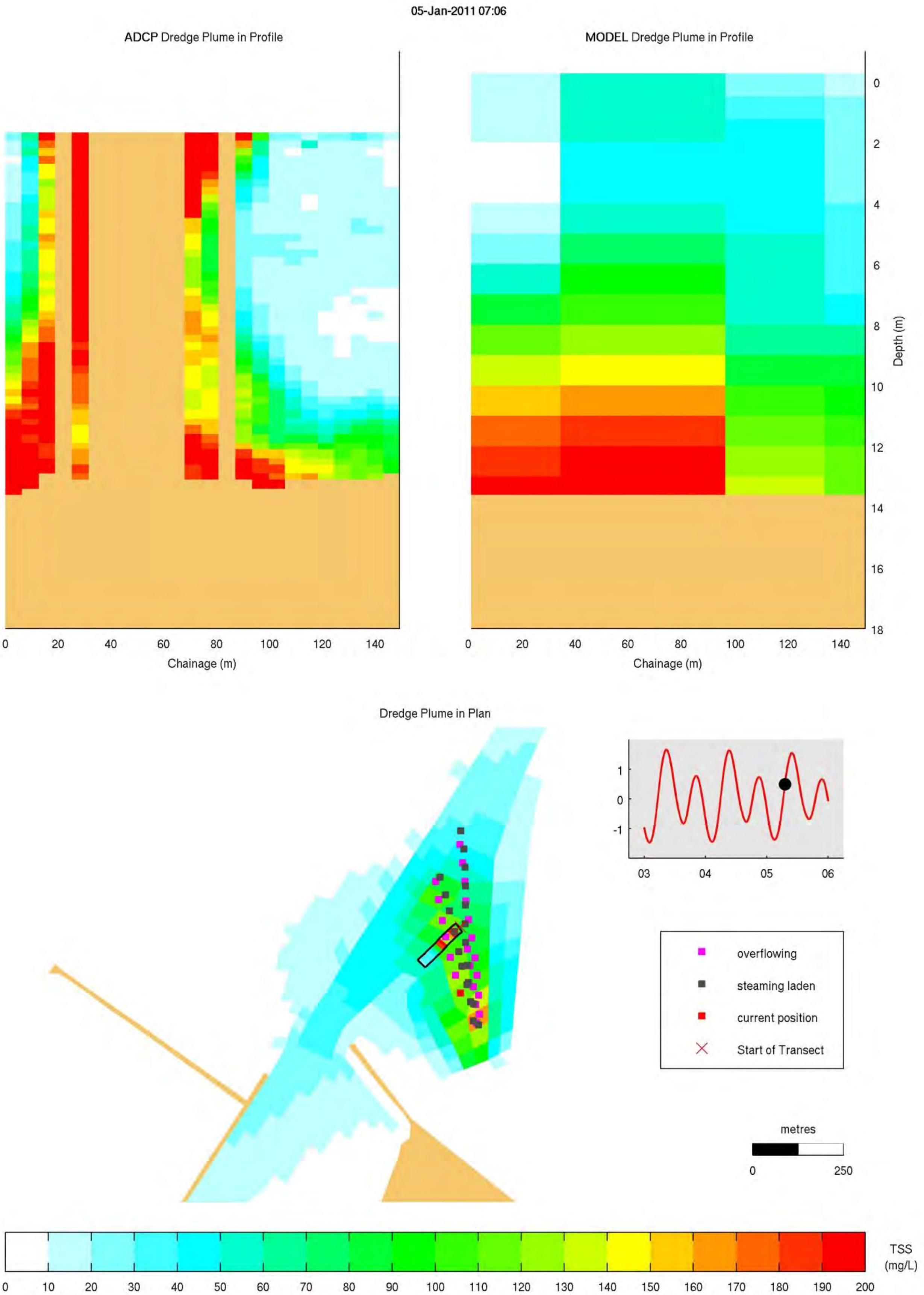


Dredge Plume Model Calibration Plots

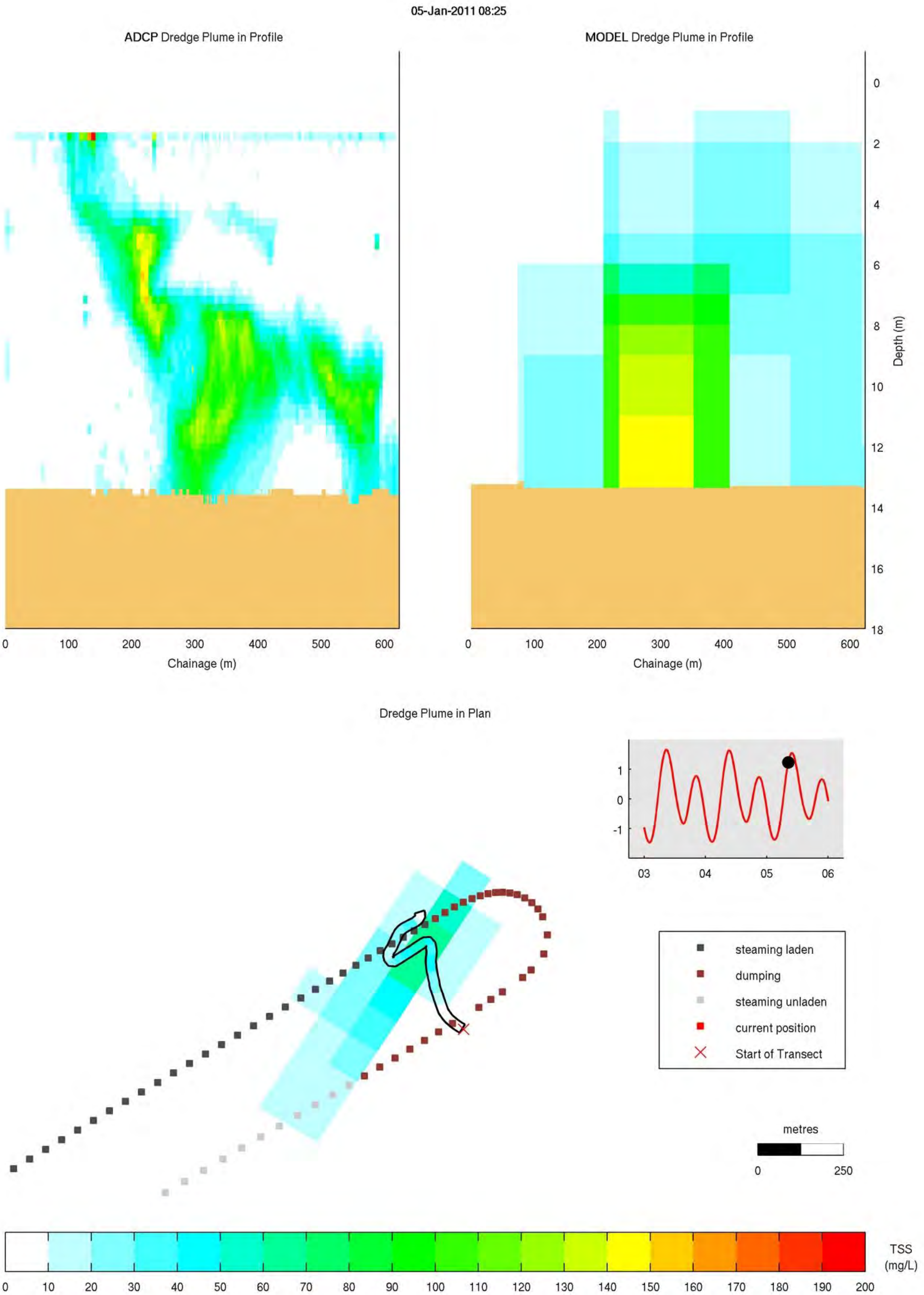


BMT WBM

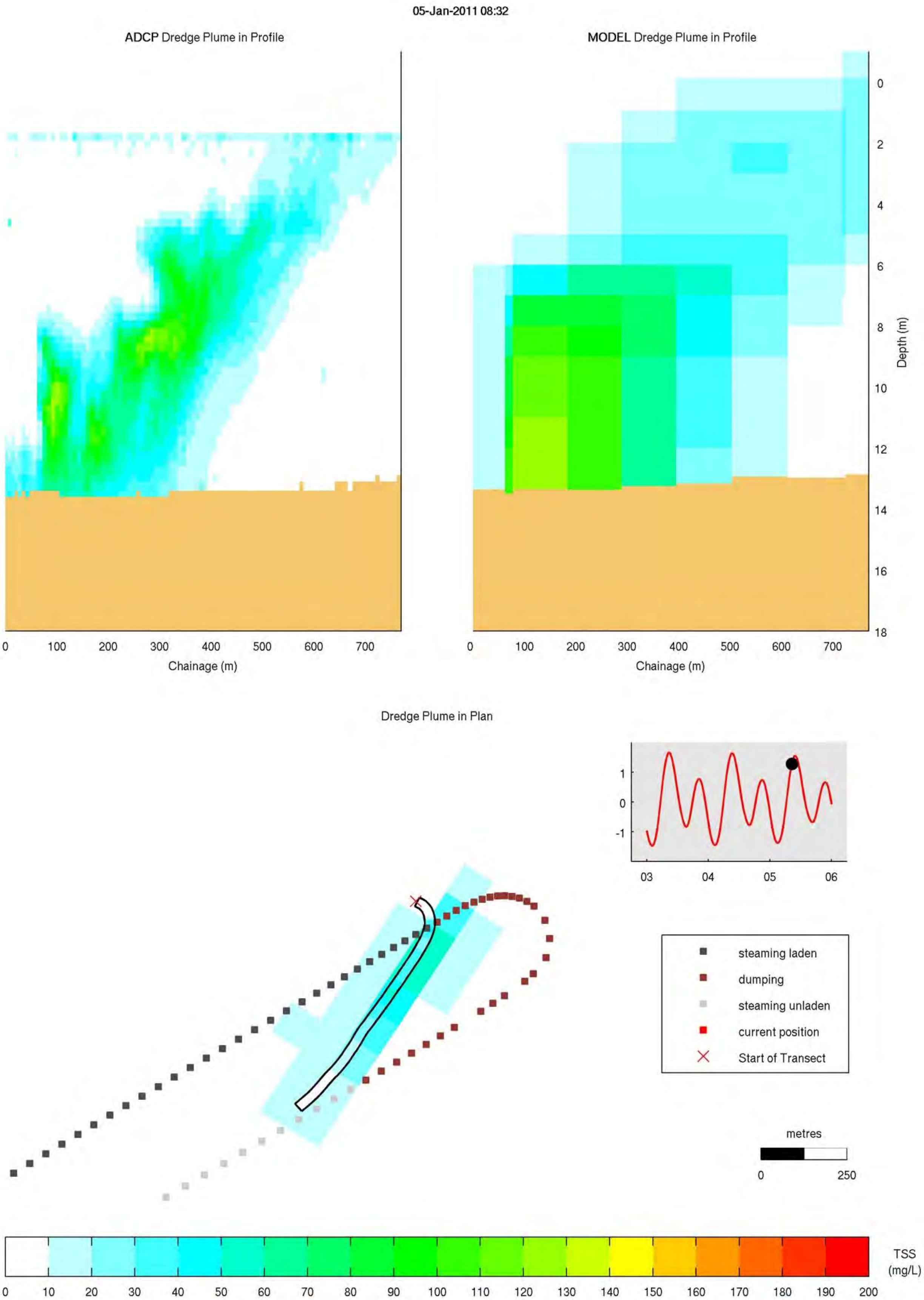
Dredge Plume Model Calibration Plots

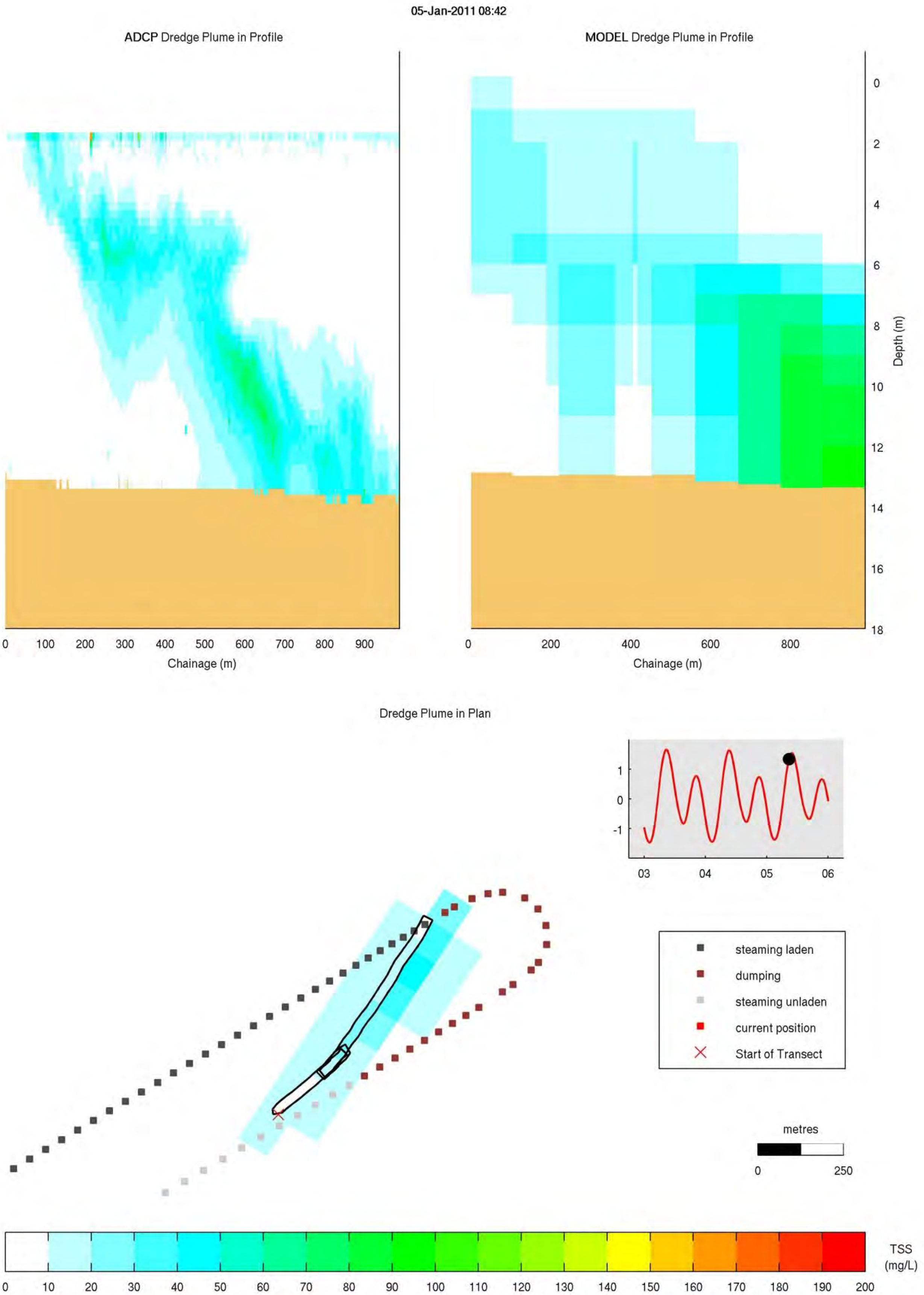


BMT WBM

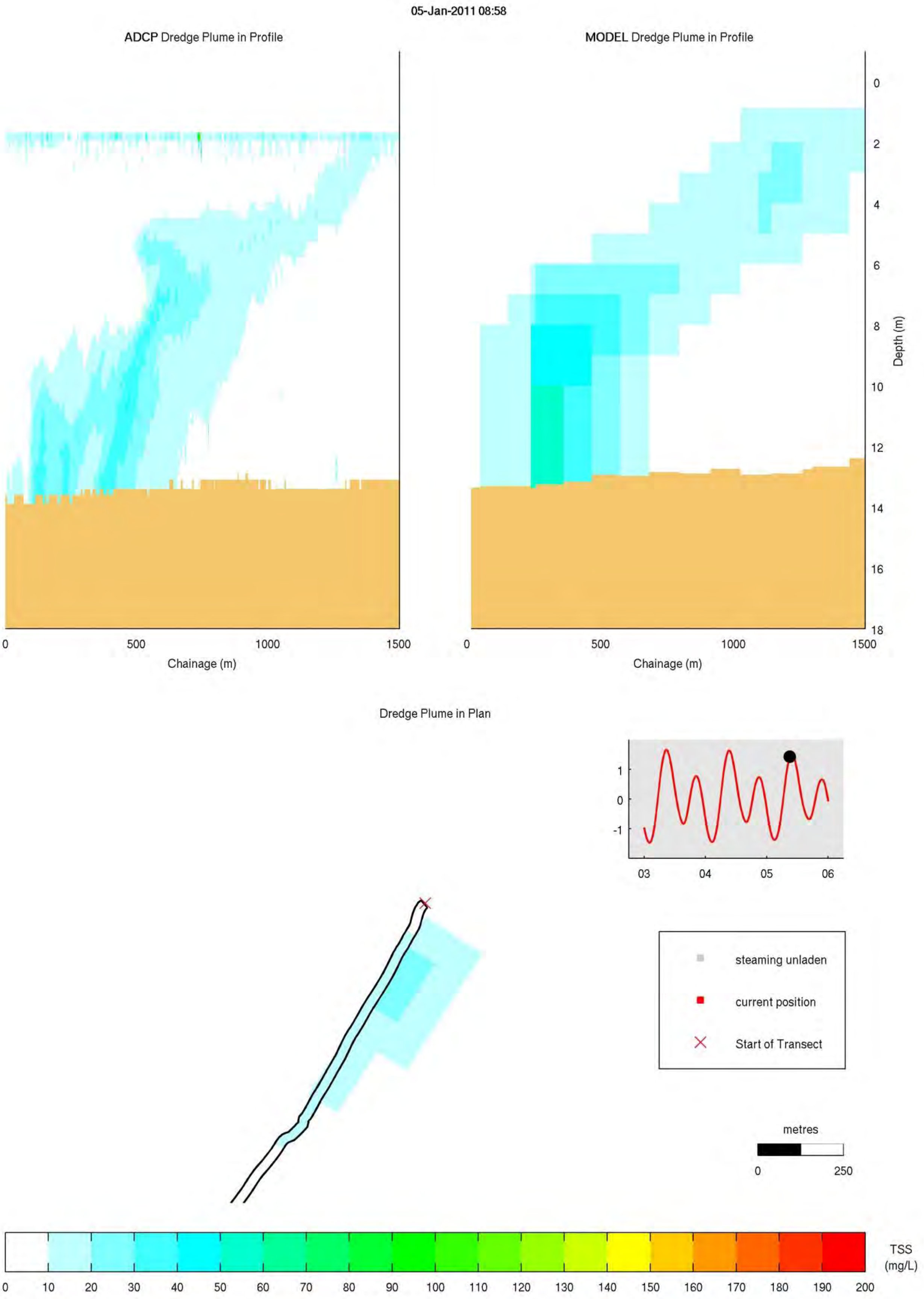

05-Jan-2011 08:25
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)

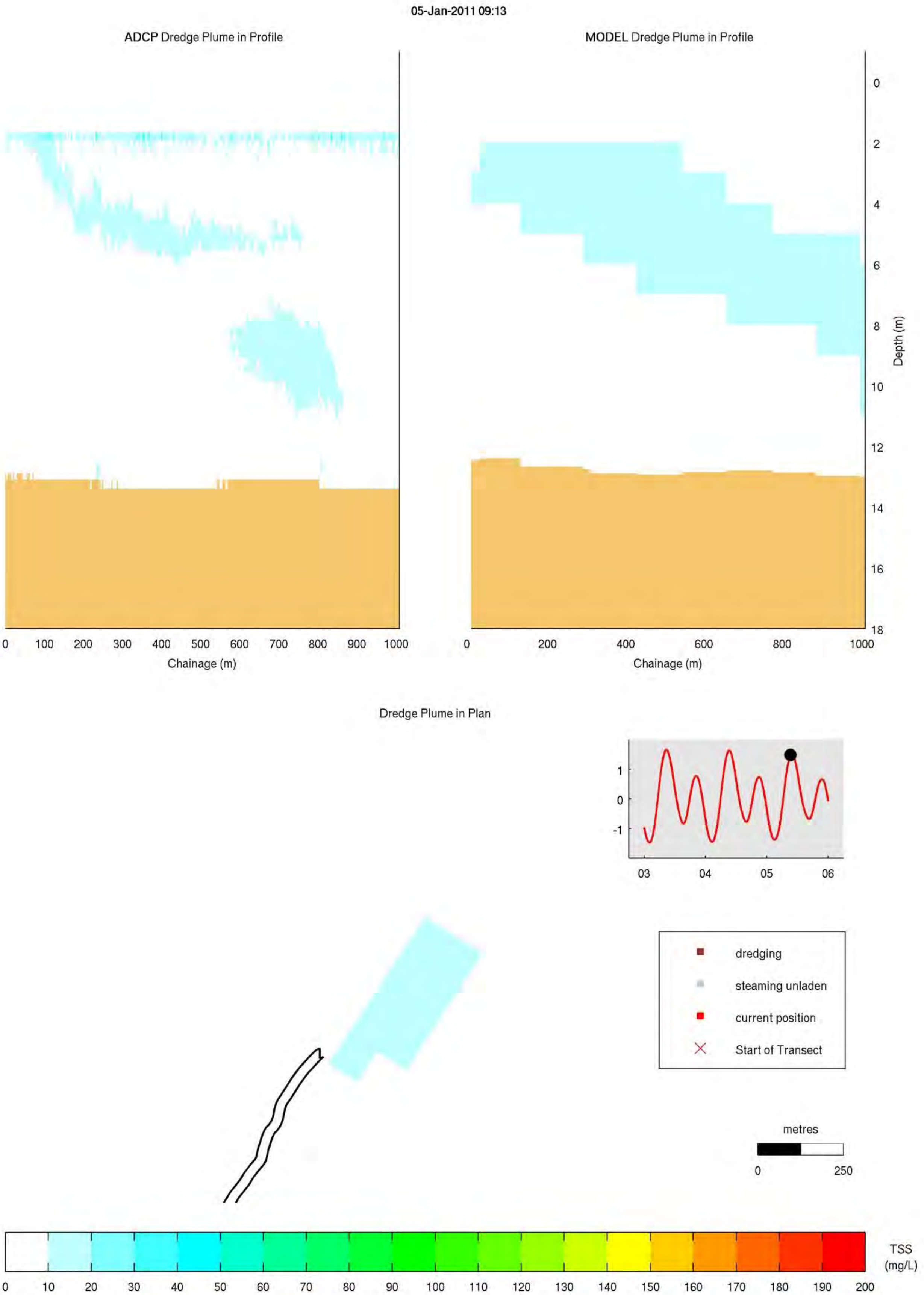
Dredge Plume Model Calibration Plots

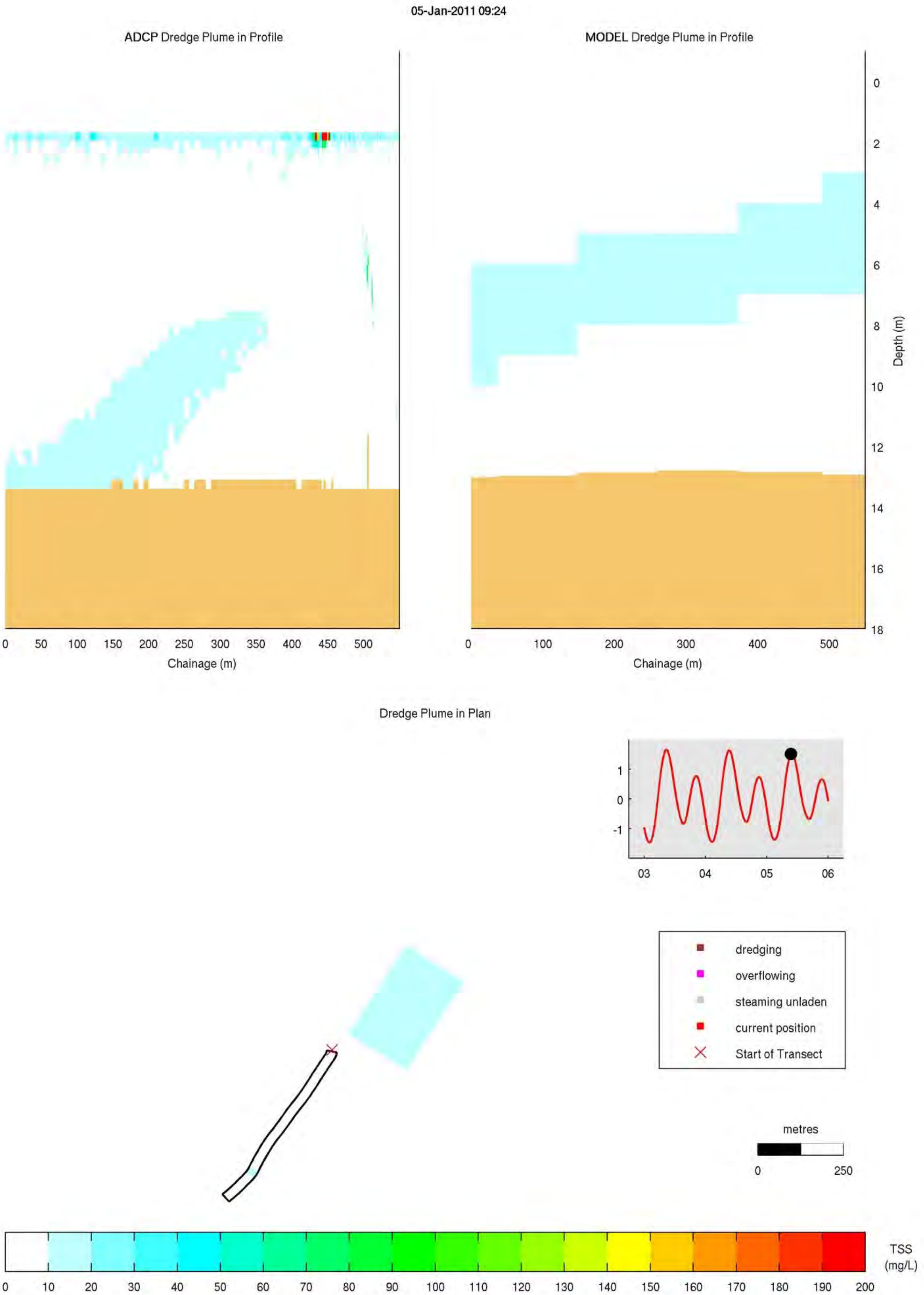


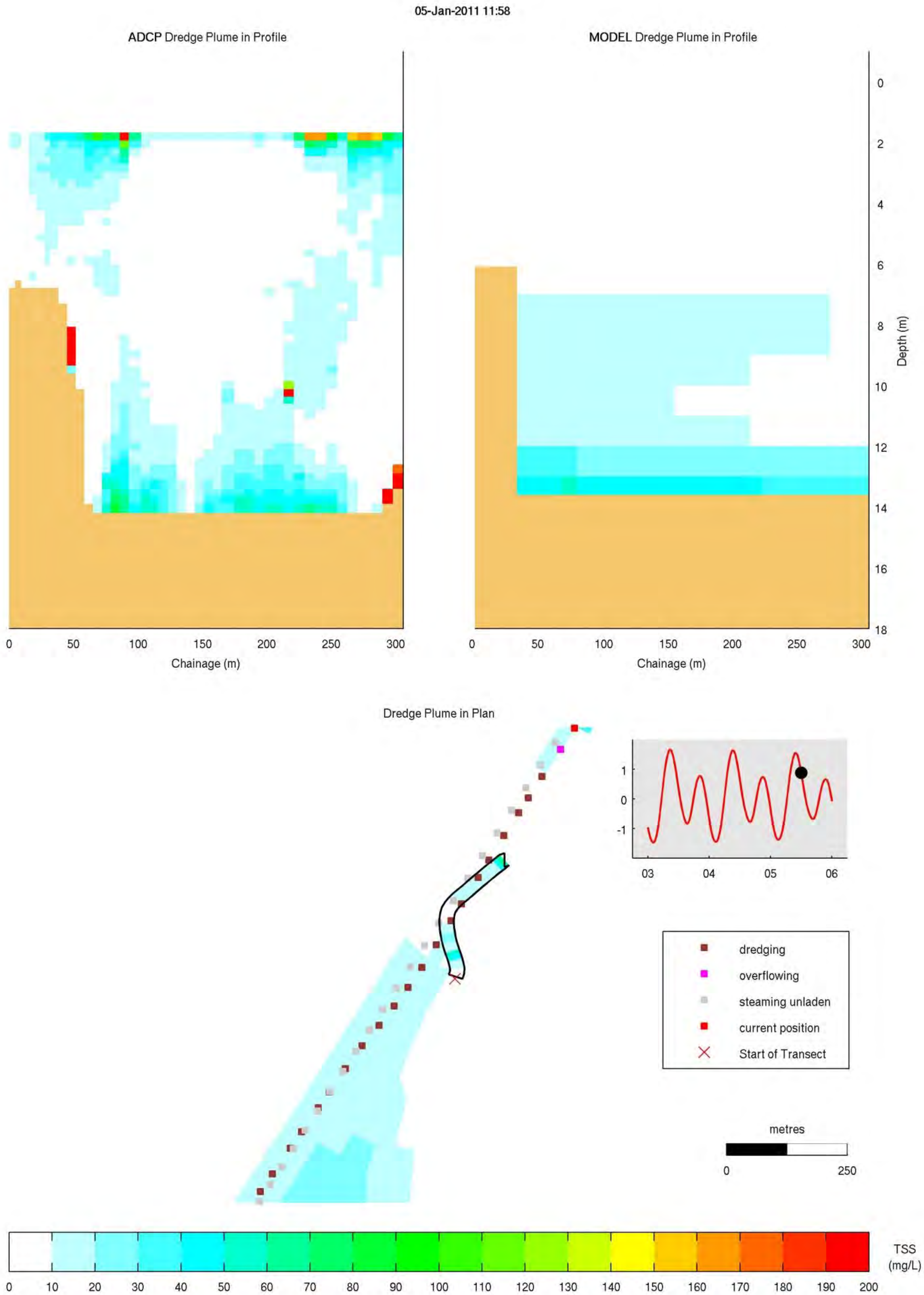

05-Jan-2011 08:42
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
100
200
300
400
500
600
700
800
900
Chainage (m)
0
200
400
600
800
Chainage (m)
0
2
4
6
8
10
12
14
16
18
Depth (m)
Dredge Plume in Plan
1
0
-1
03
04
05
06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TSS
(mg/L)

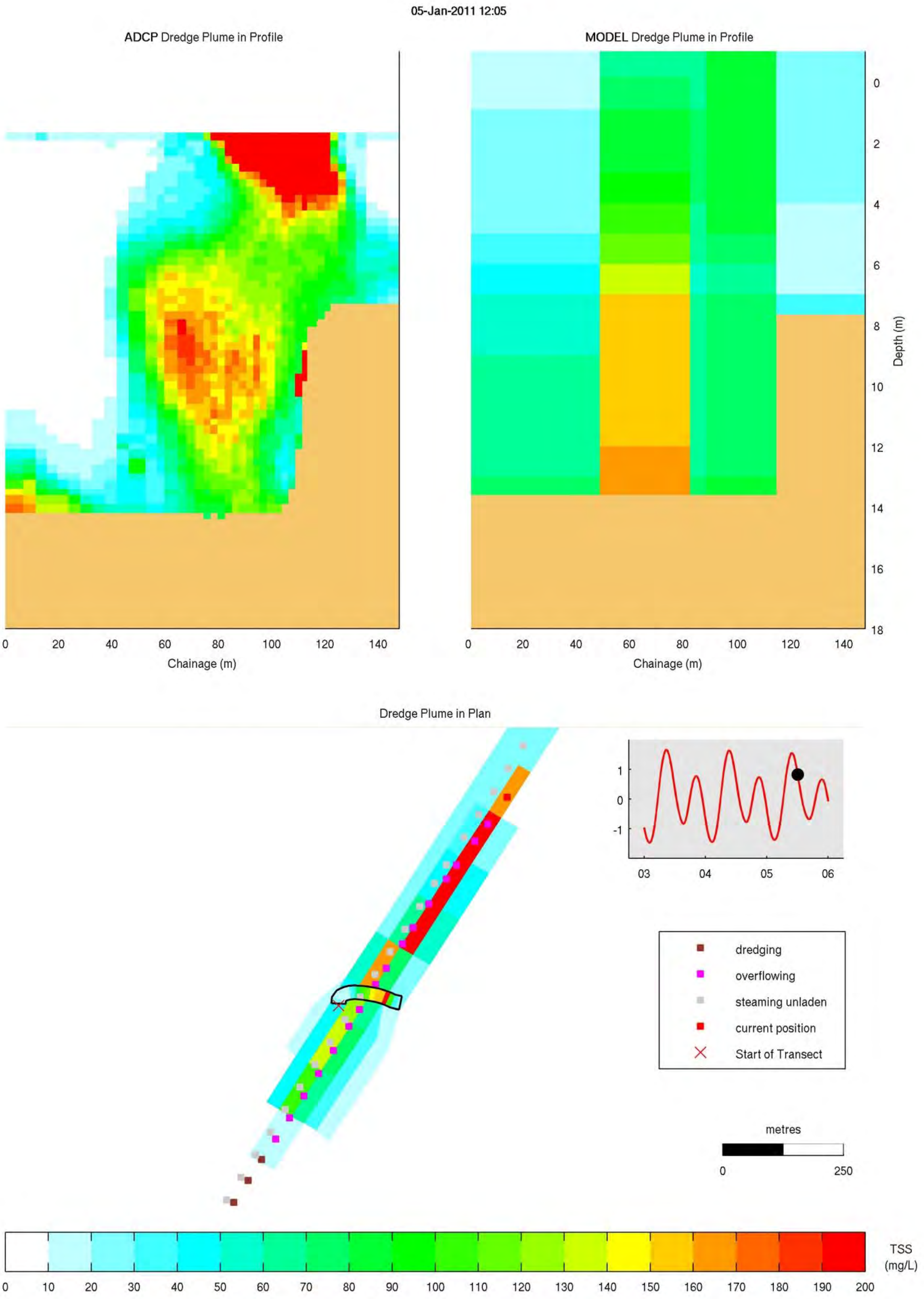
Dredge Plume Model Calibration Plots

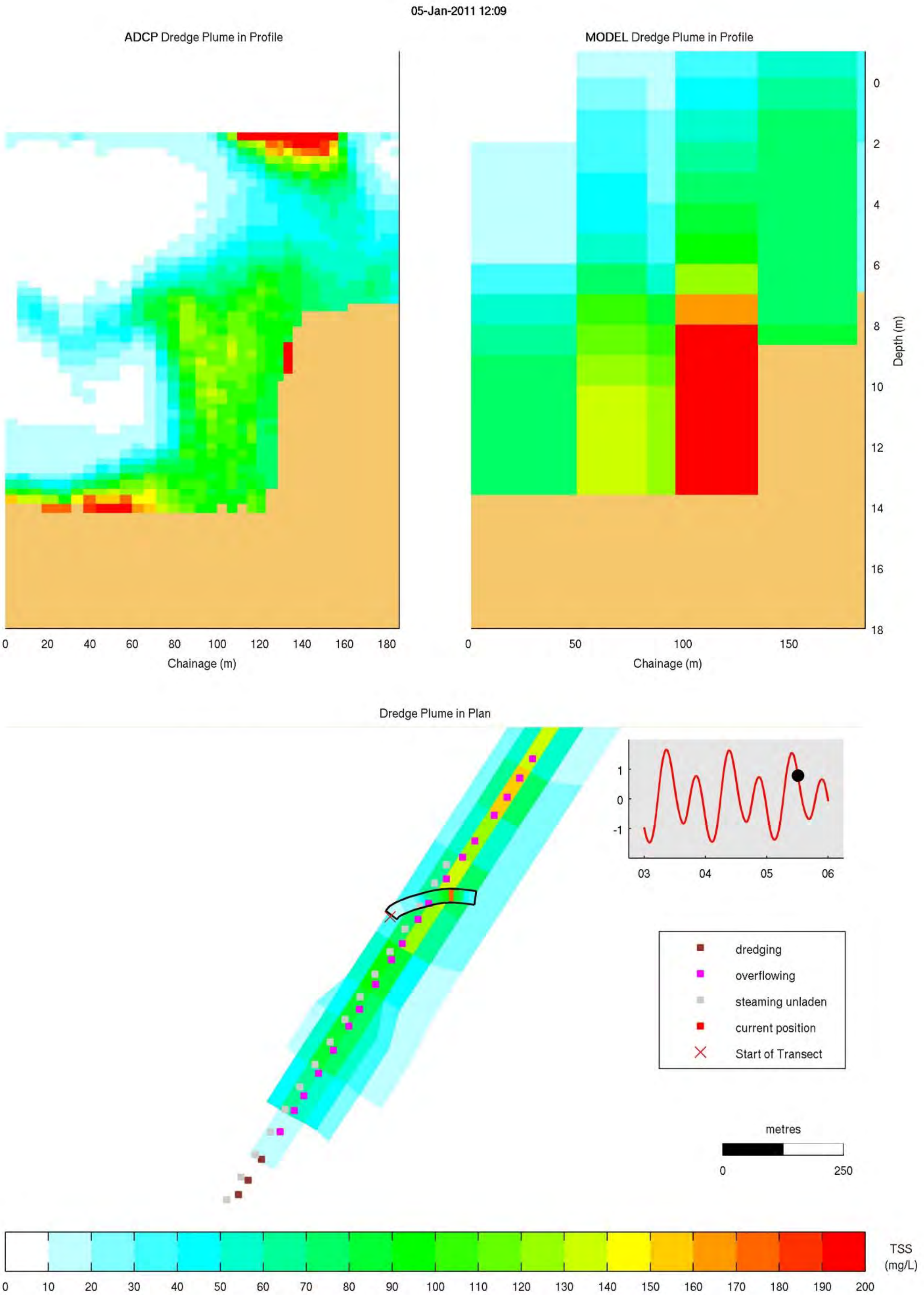



05-Jan-2011 09:13
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 100 200 300 400 500 600 700 800 900 1000
Chainage (m)
0 200 400 600 800 1000
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

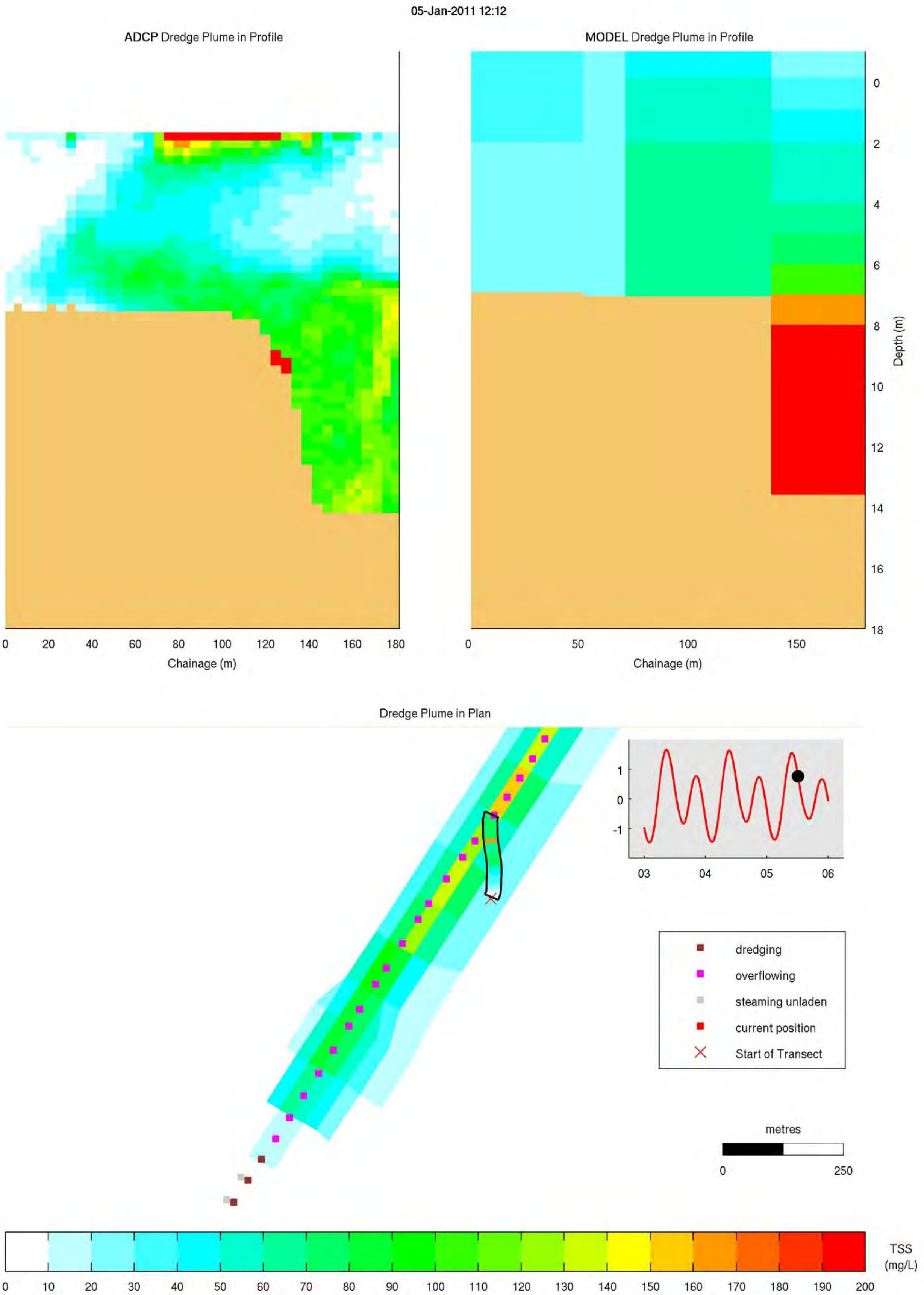

05-Jan-2011 09:24
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 50 100 150 200 250 300 350 400 450 500
Chainage (m)
0 100 200 300 400 500
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS (mg/L)


05-Jan-2011 11:58
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

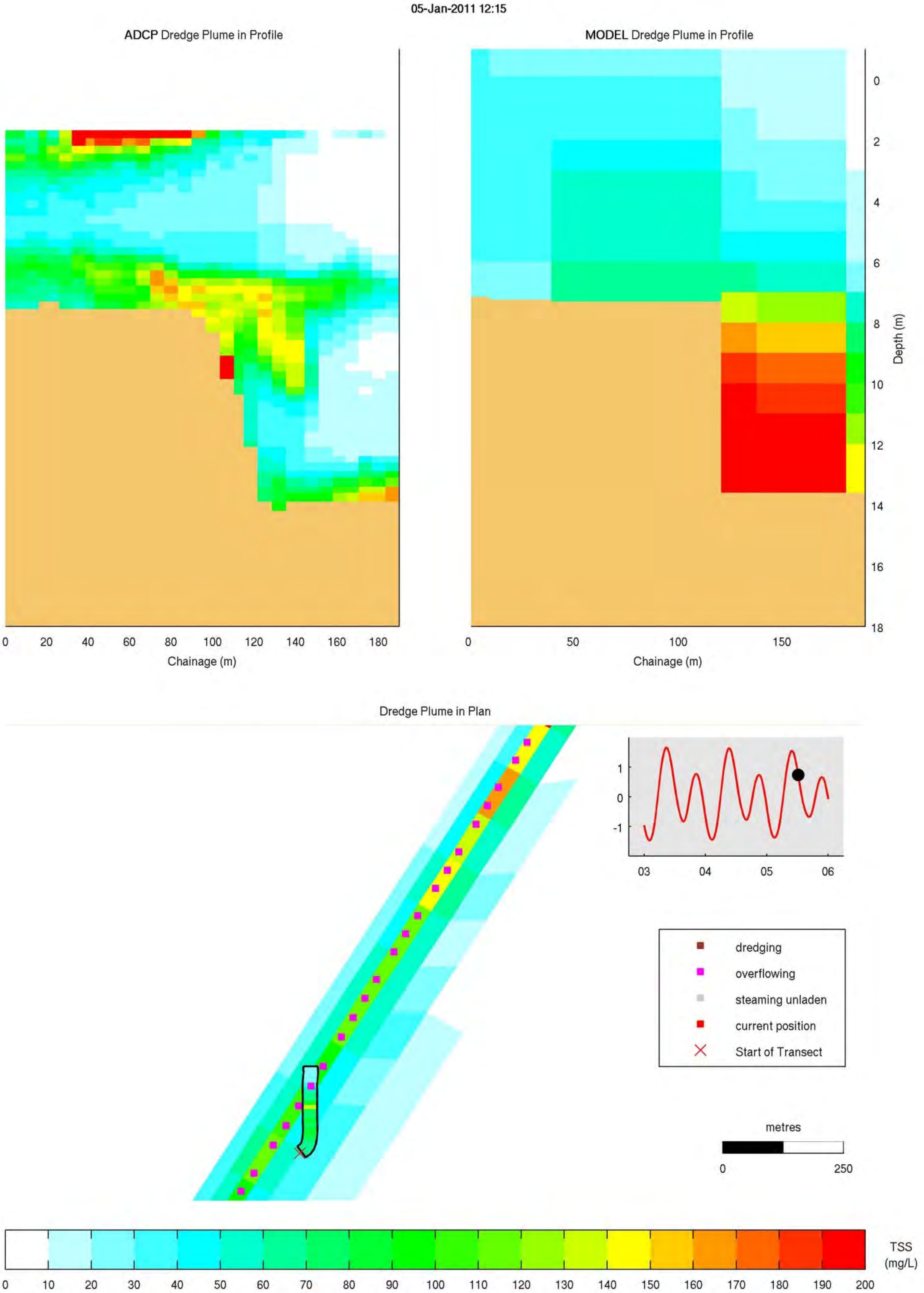

05-Jan-2011 12:05
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

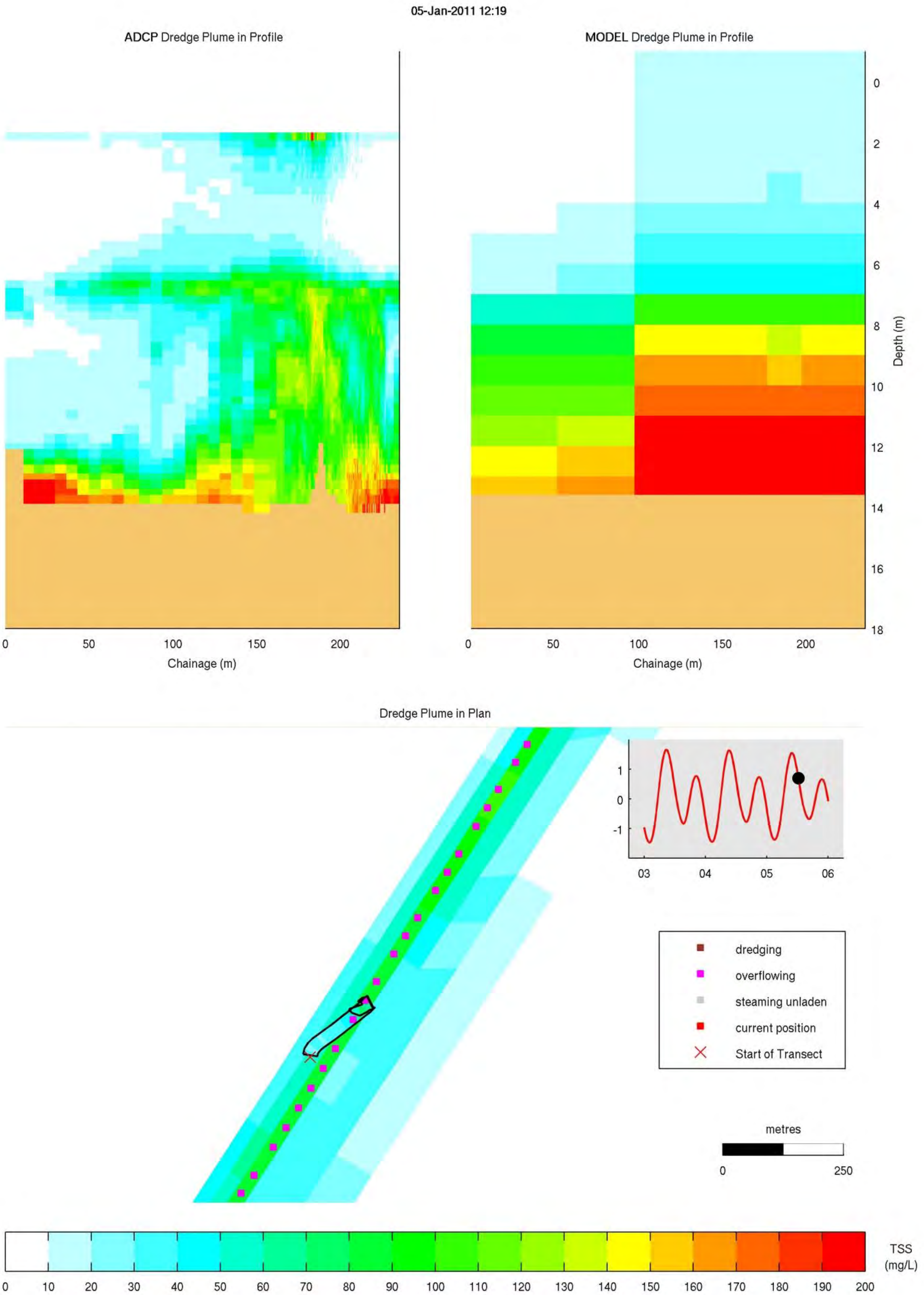

05-Jan-2011 12:09
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

Dredge Plume Model Calibration Plots



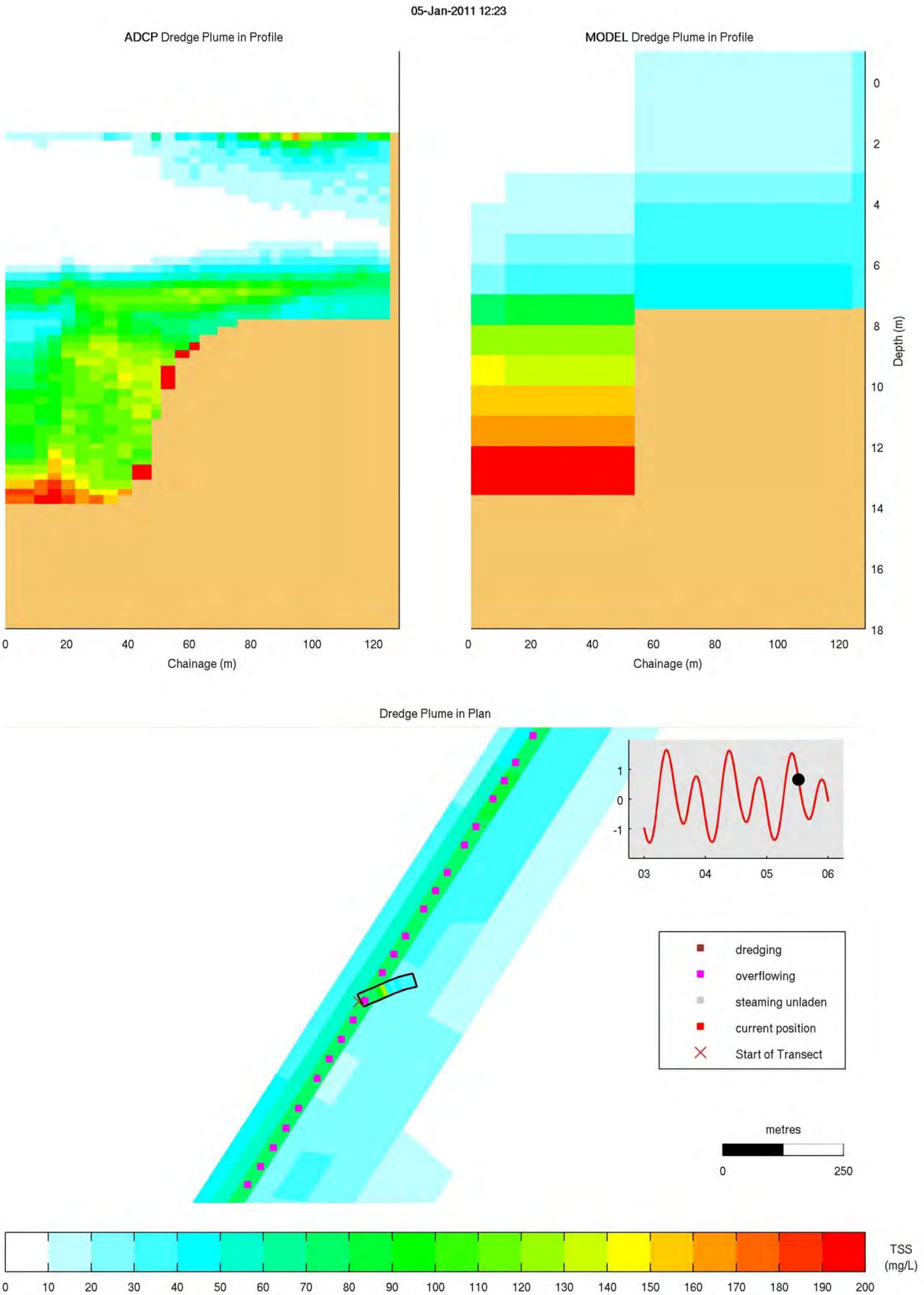
BMT WBM

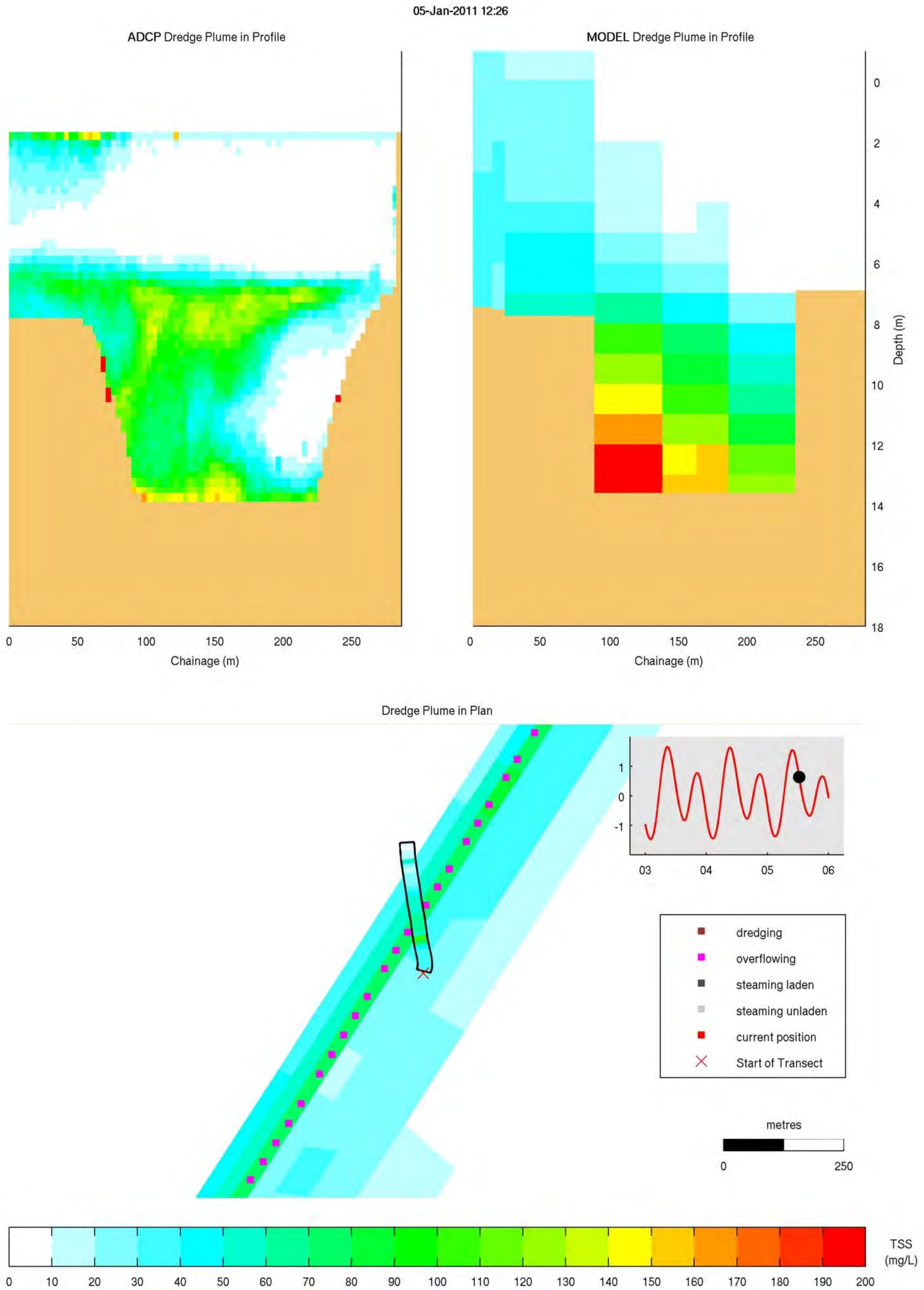

05-Jan-2011 12:15
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
2
4
6
8
10
12
14
16
18
Depth (m)
0 20 40 60 80 100 120 140 160 180
Chainage (m)
0 50 100 150
Chainage (m)
Dredge Plume in Plan
1
0
-1
03 04 05 06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0 250
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
TSS
(mg/L)

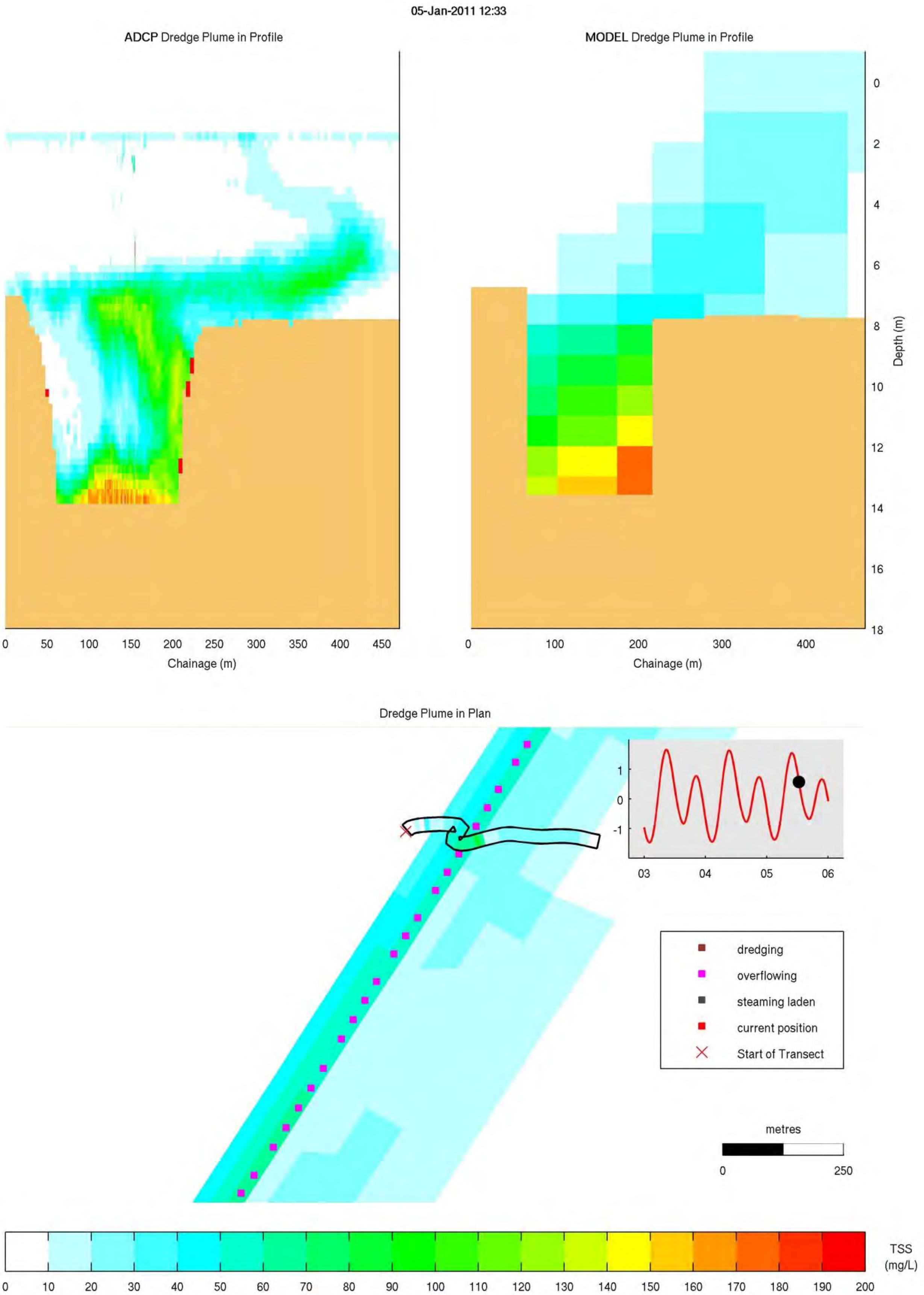

05-Jan-2011 12:19
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

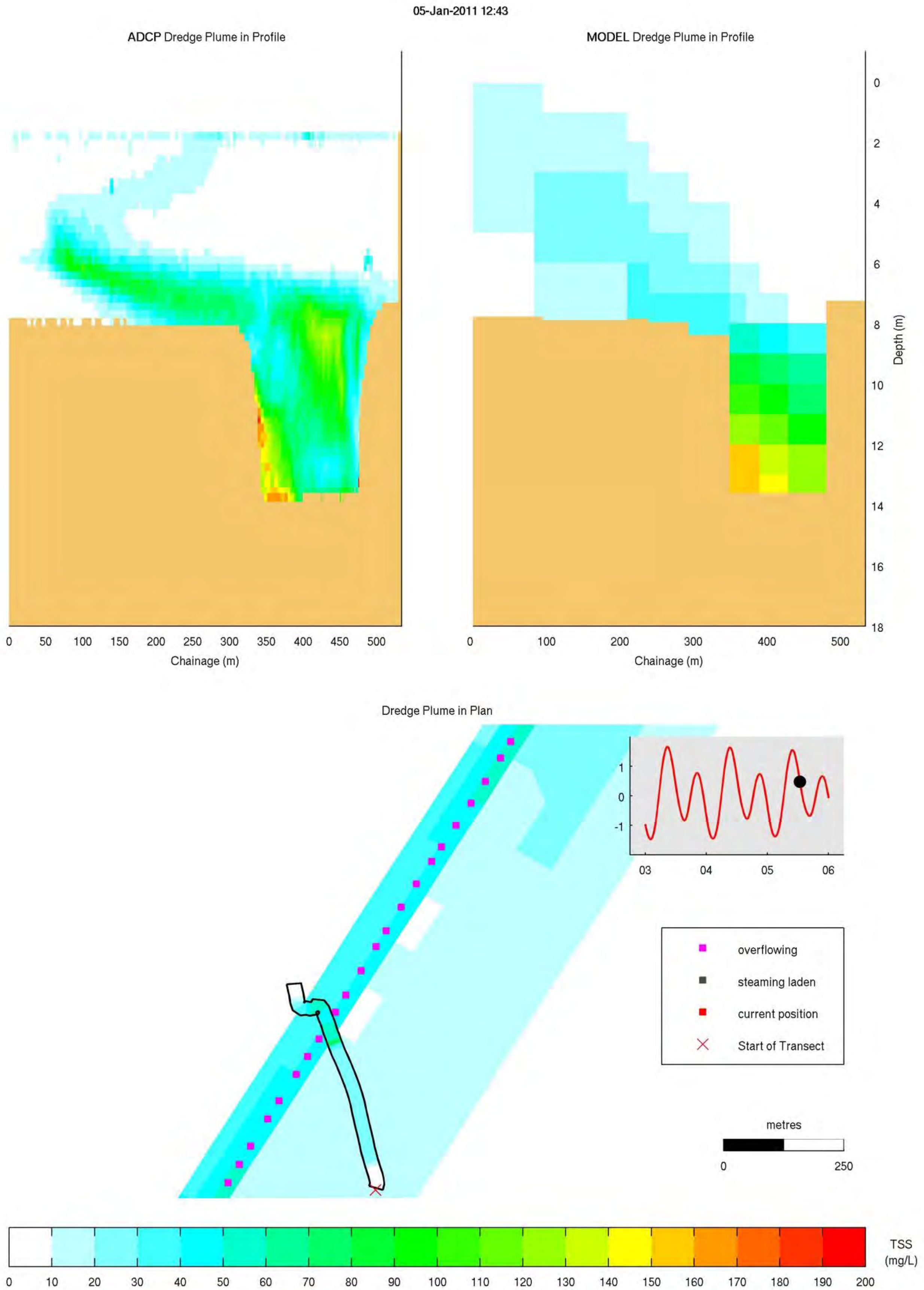
BMT WBM

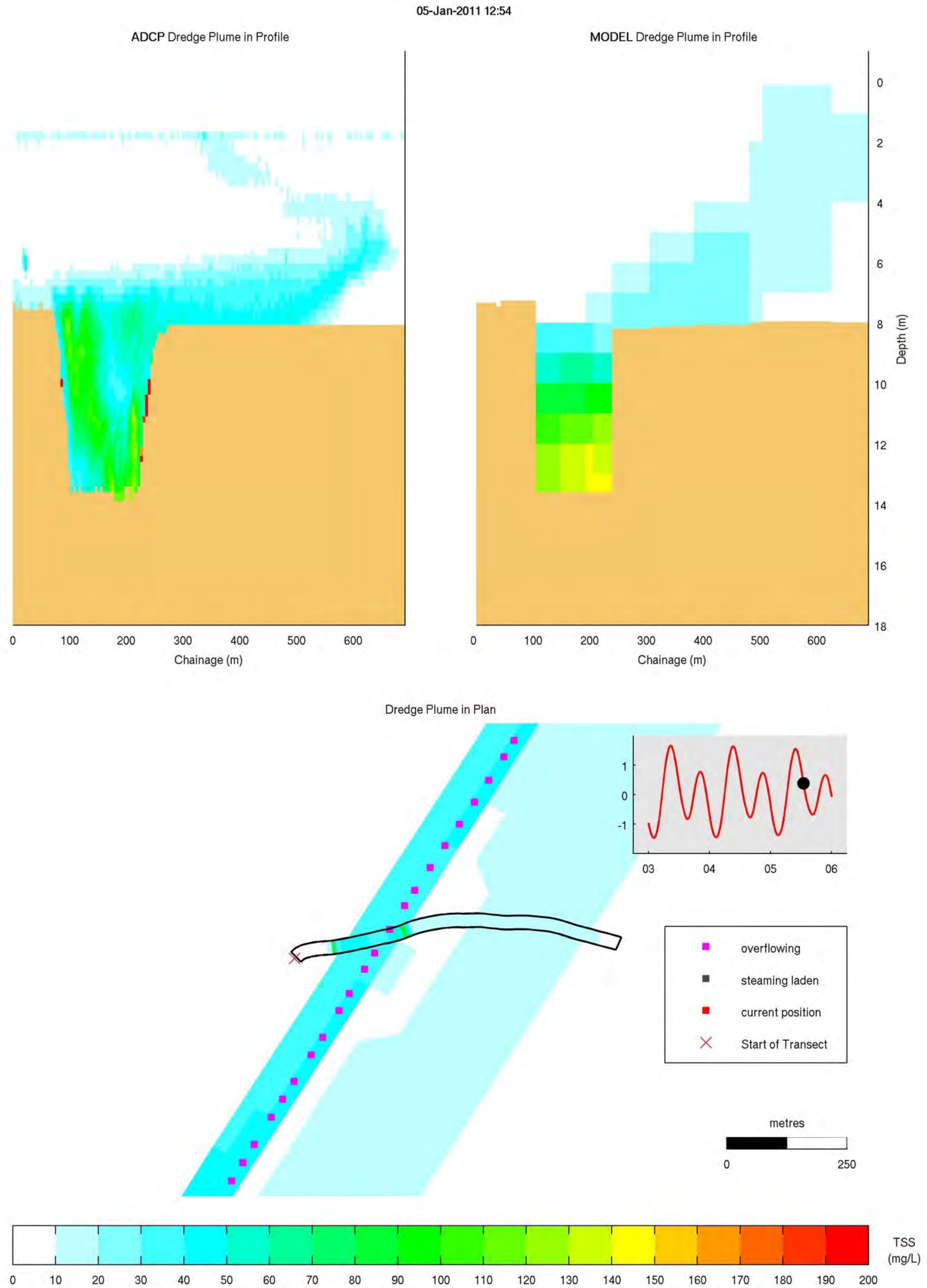
Dredge Plume Model Calibration Plots



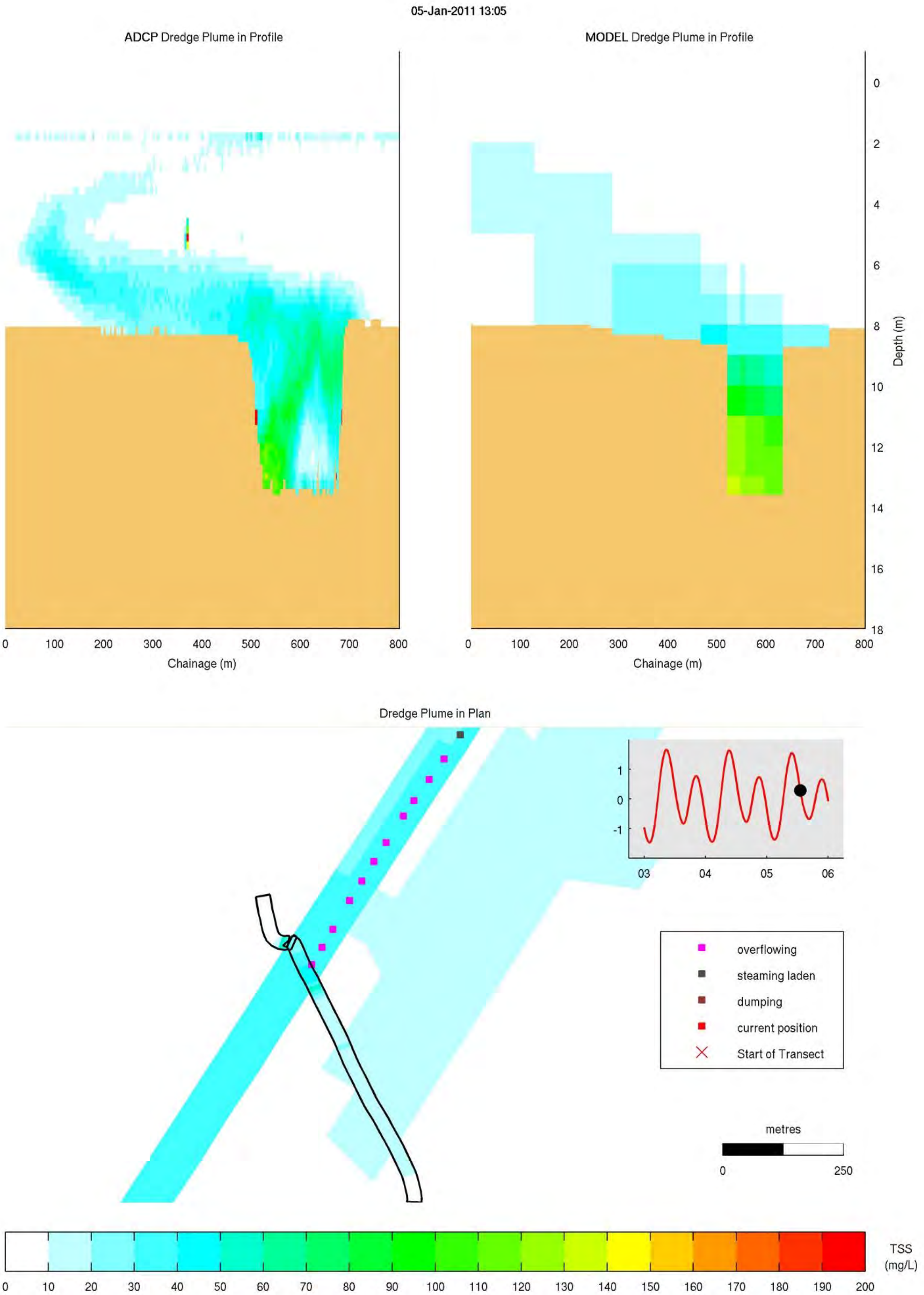

05-Jan-2011 12:26
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
03
04
05
06
dredging
overflowing
steaming laden
steaming unladen
current position
Start of Transect
metres
0
250
TSS
(mg/L)

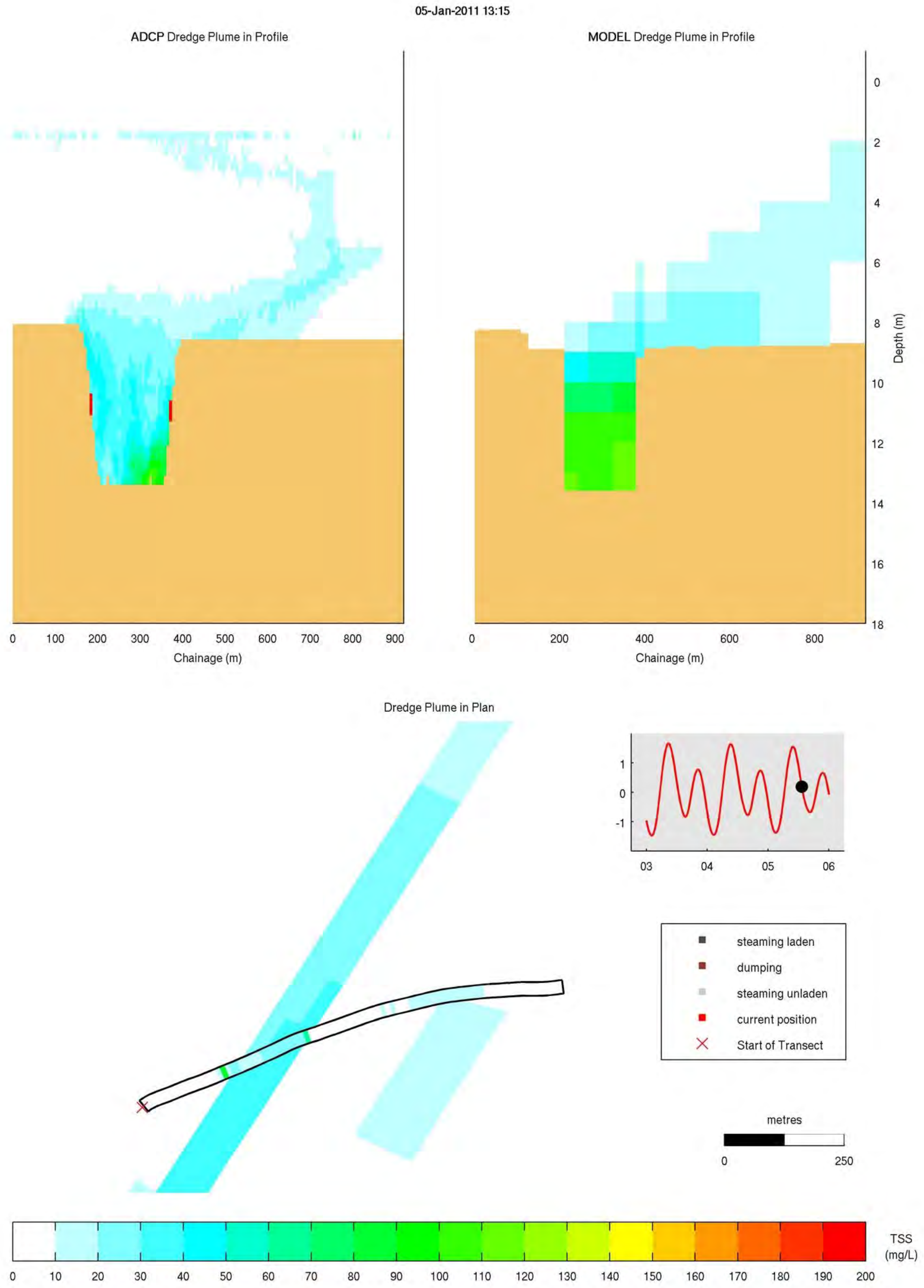

05-Jan-2011 12:33
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Chainage (m)
Dredge Plume in Plan
dredging
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

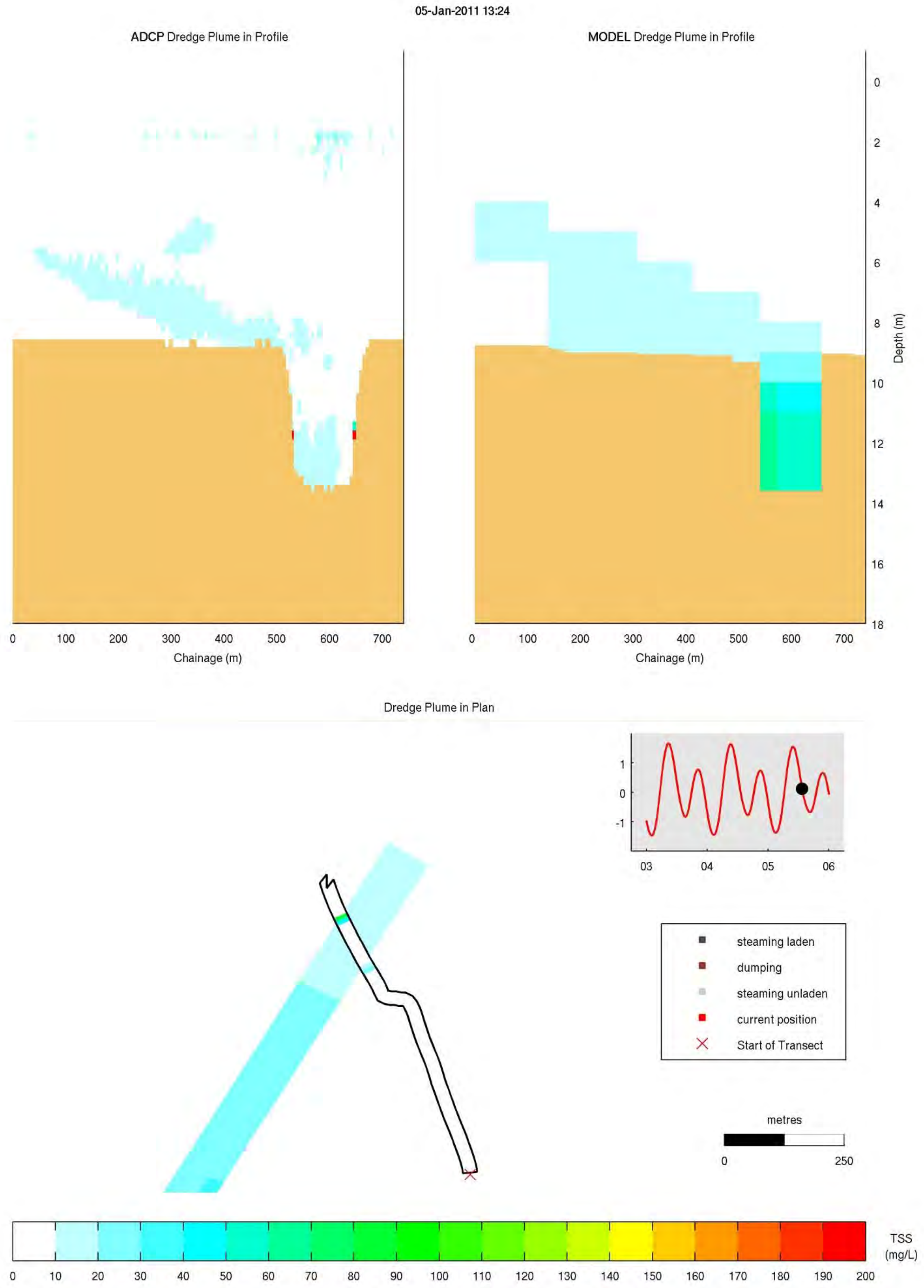

05-Jan-2011 12:43
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Chainage (m)
Depth (m)
Dredge Plume in Plan
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS (mg/L)


05-Jan-2011 12:54
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Depth (m)
Chainage (m)
Dredge Plume in Plan
overflowing
steaming laden
current position
Start of Transect
metres
0
250
TSS
(mg/L)

Dredge Plume Model Calibration Plots



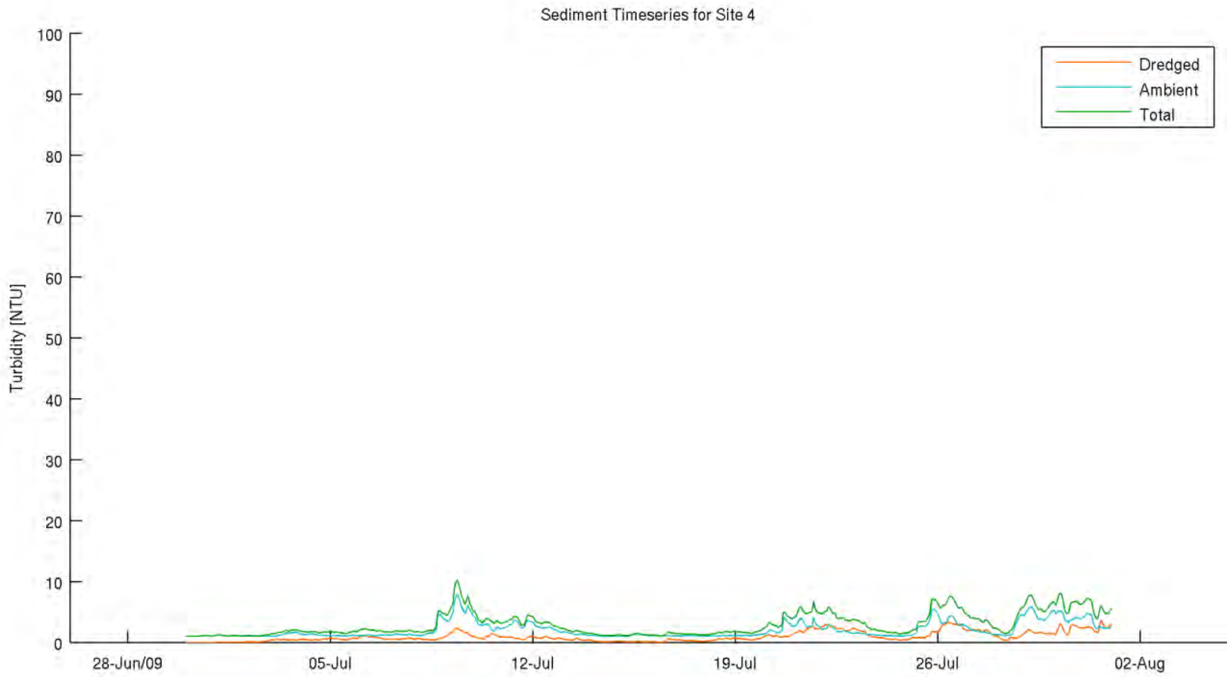

05-Jan-2011 13:15
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
Chainage (m)
Depth (m)
Dredge Plume in Plan
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

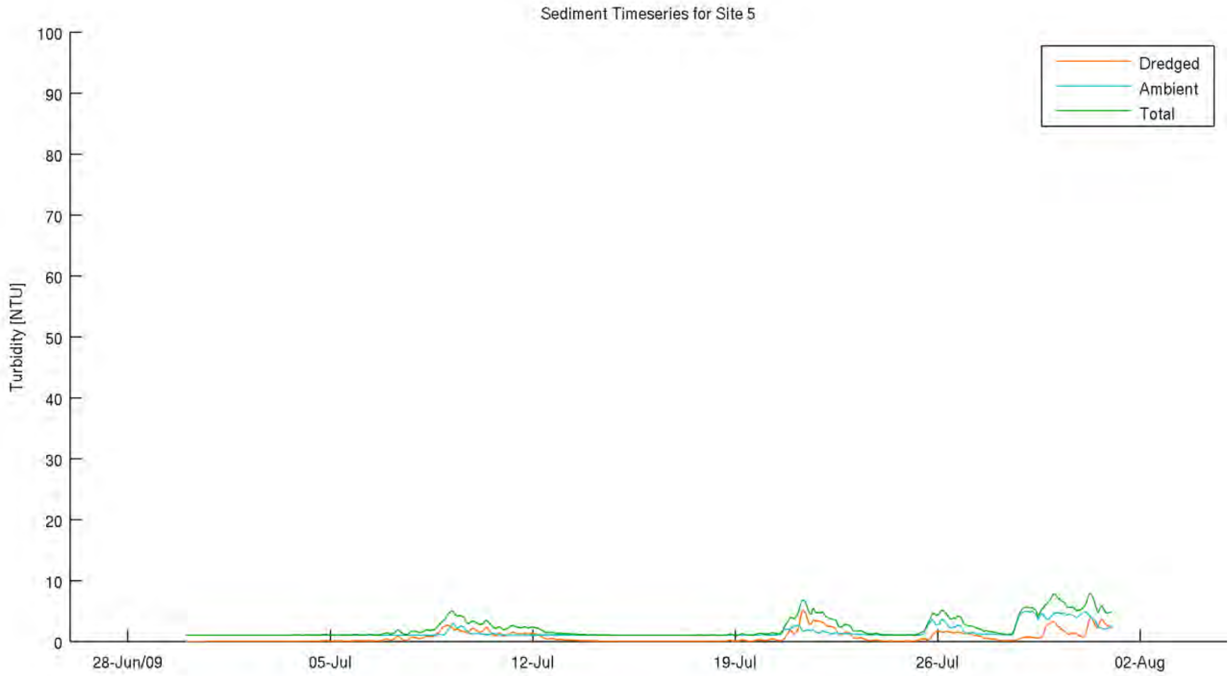

05-Jan-2011 13:24
ADCP Dredge Plume in Profile
MODEL Dredge Plume in Profile
0
100
200
300
400
500
600
700
Chainage (m)
Depth (m)
0
2
4
6
8
10
12
14
16
18
Dredge Plume in Plan
1
0
-1
03
04
05
06
steaming laden
dumping
steaming unladen
current position
Start of Transect
metres
0
250
TSS (mg/L)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

Appendix D Plume Modelling Time Series Output

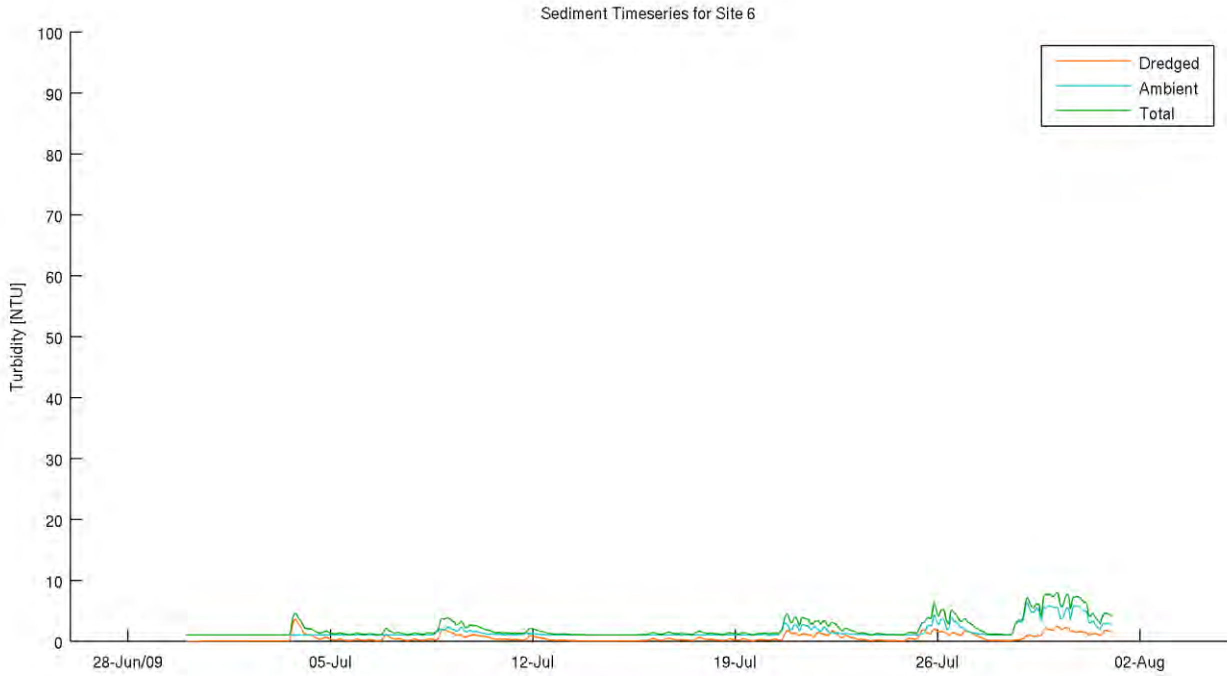
Turbidity Time Series Plots

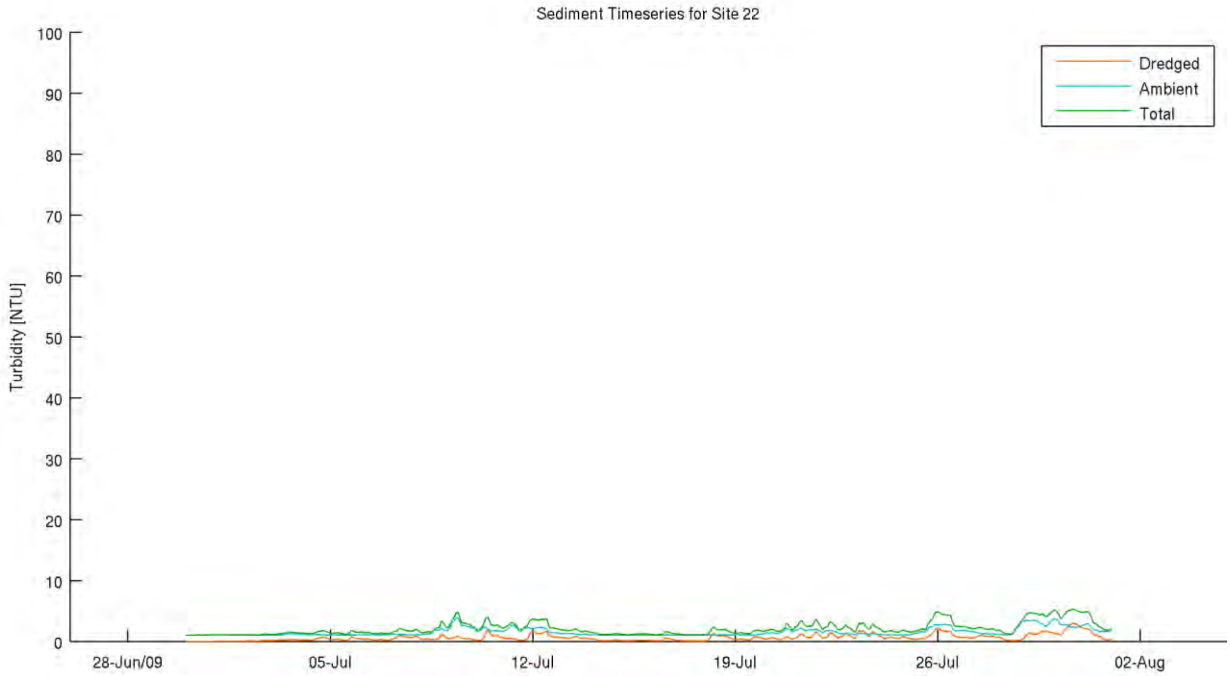
Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – July 2009 Conditions





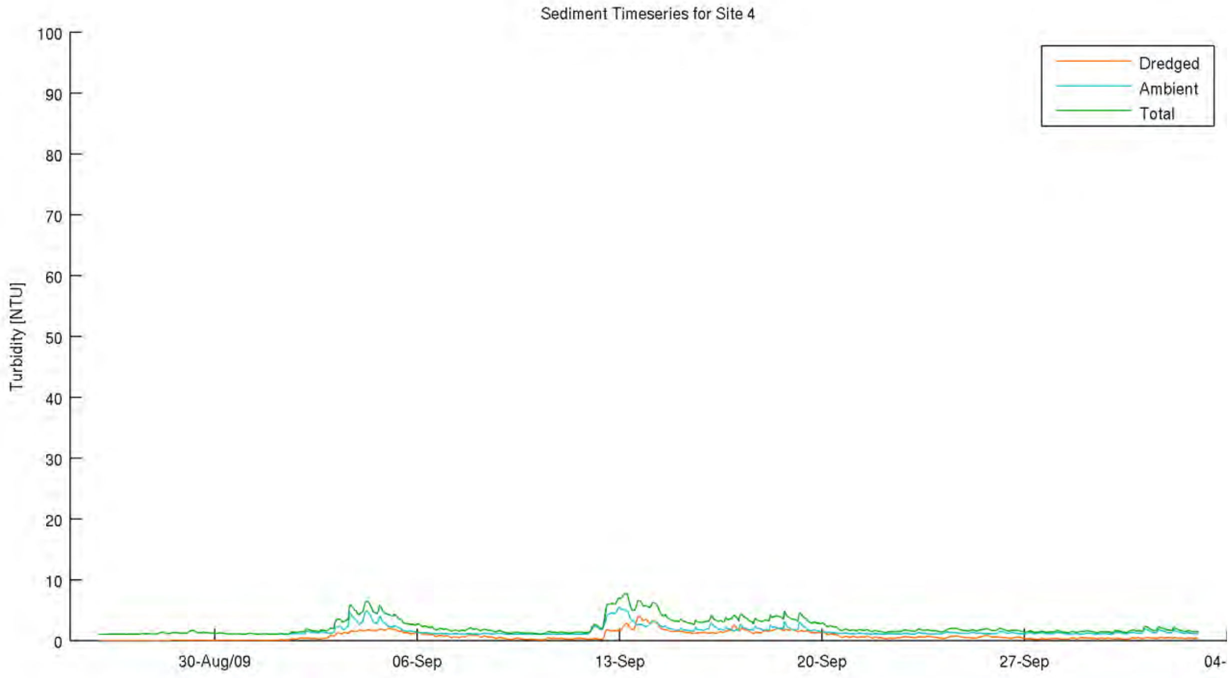
Plume Modelling Time Series Output

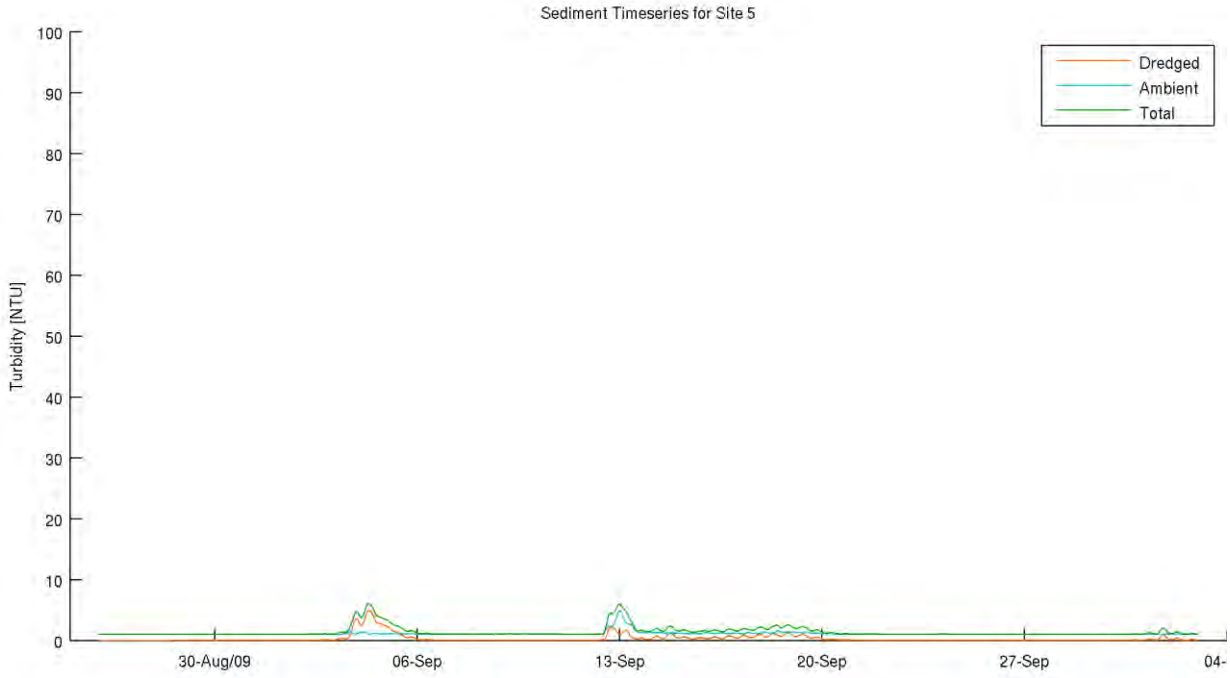




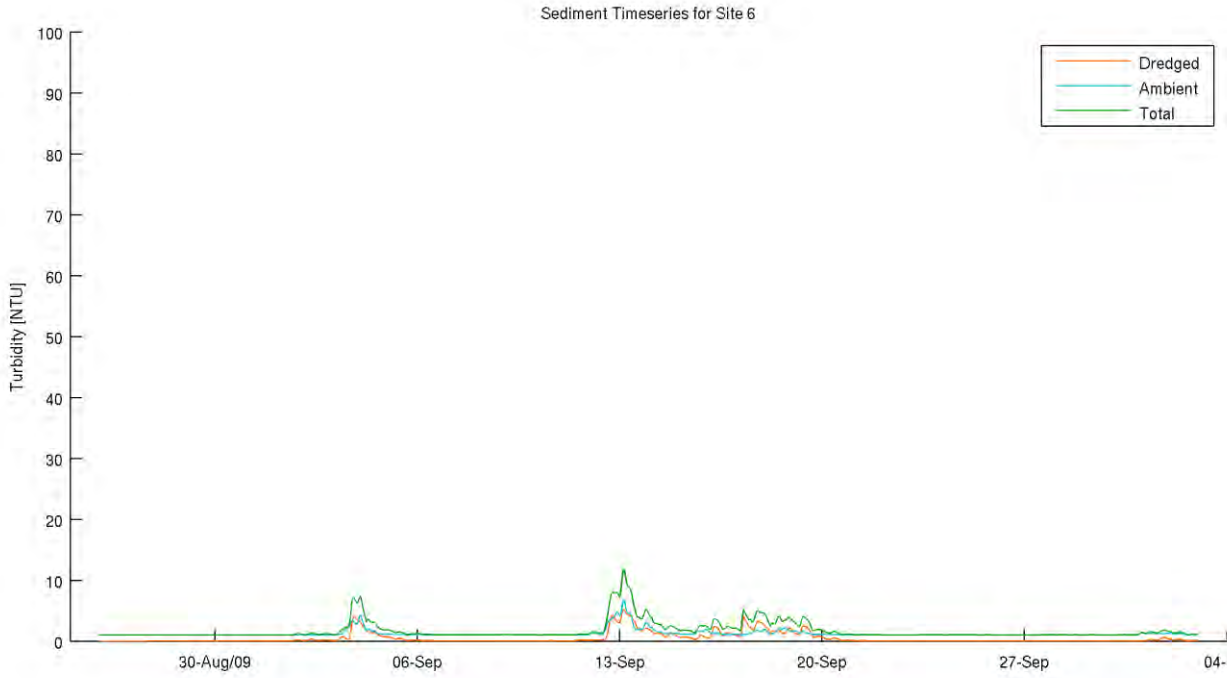
Turbidity Time Series Plots

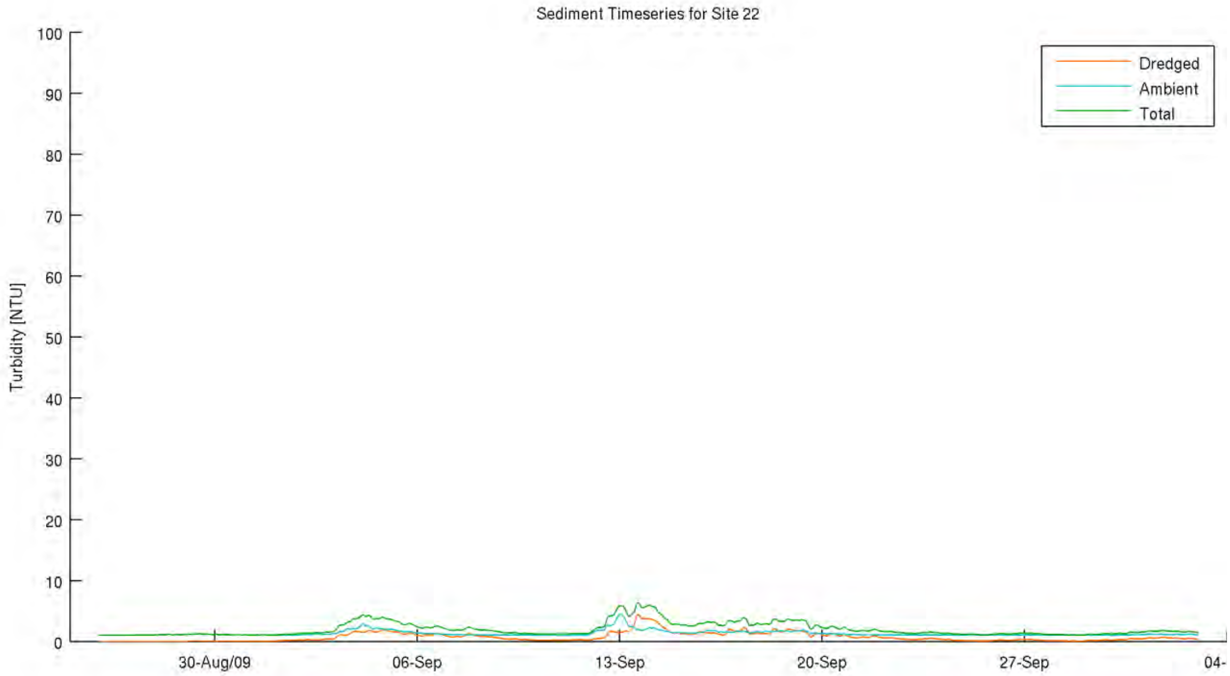
Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – September 2009 Conditions





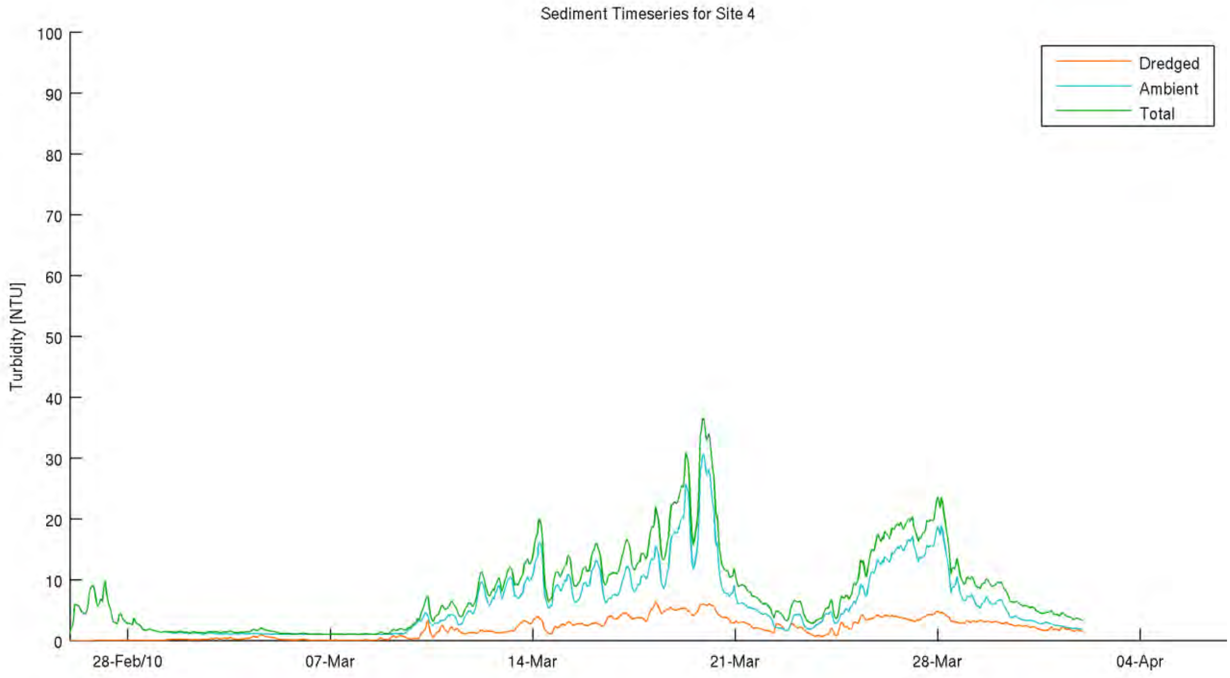
Plume Modelling Time Series Output

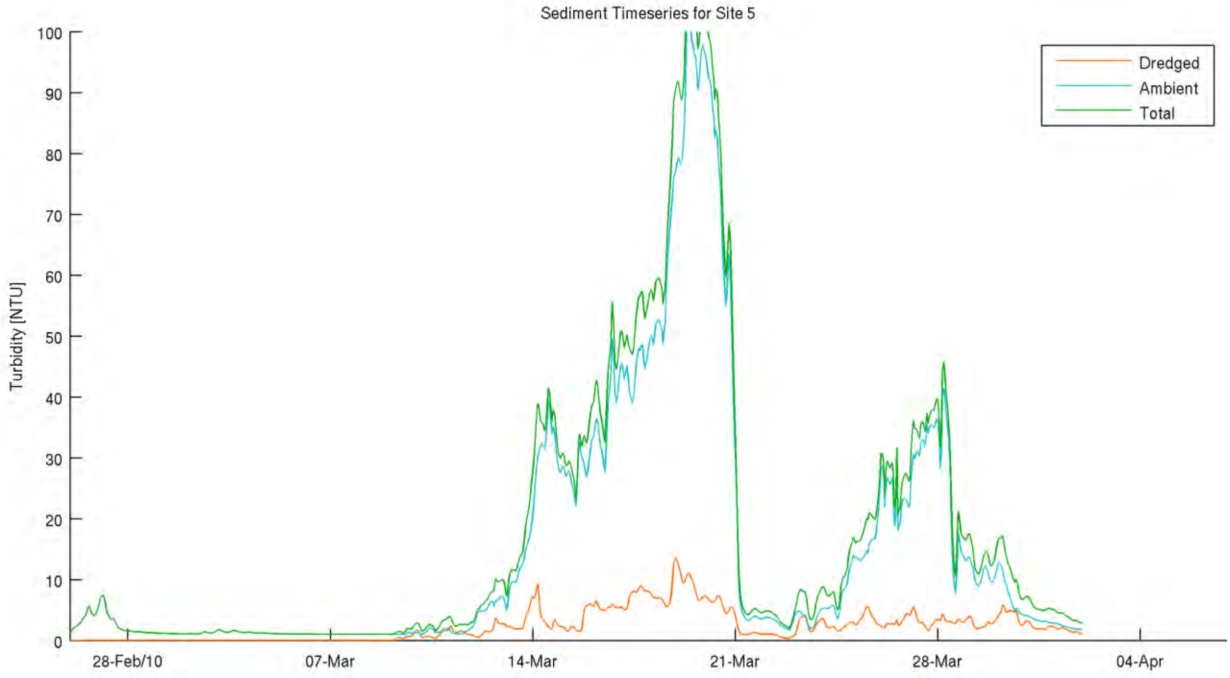


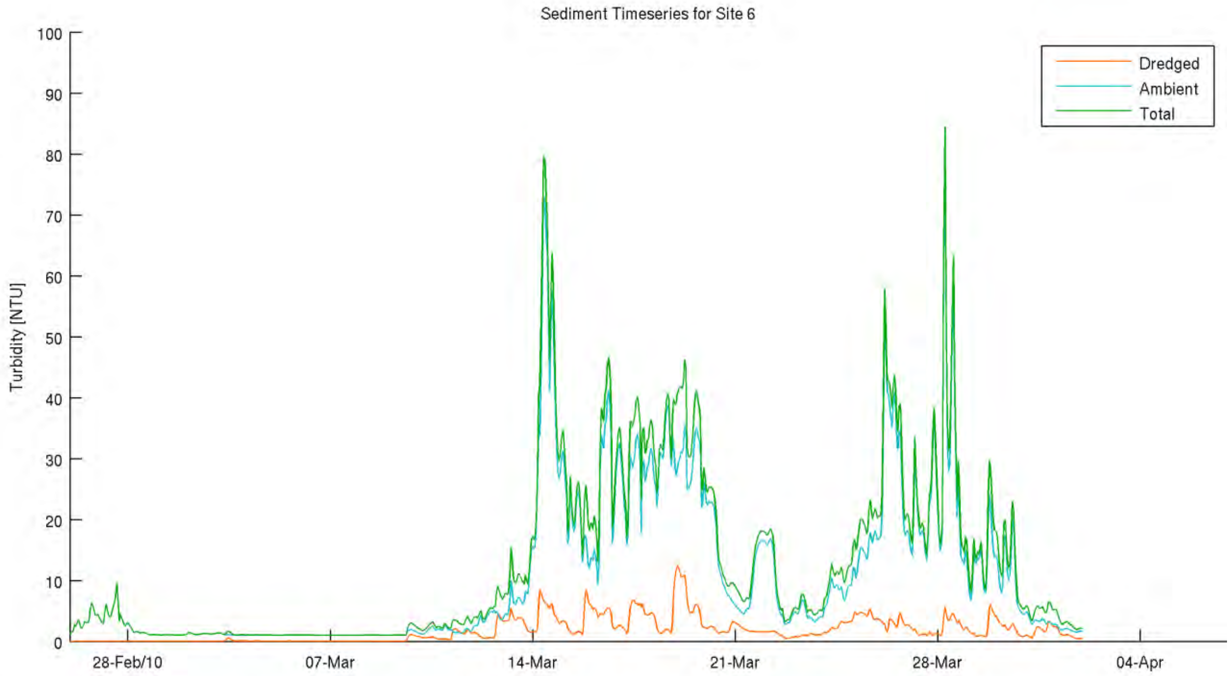


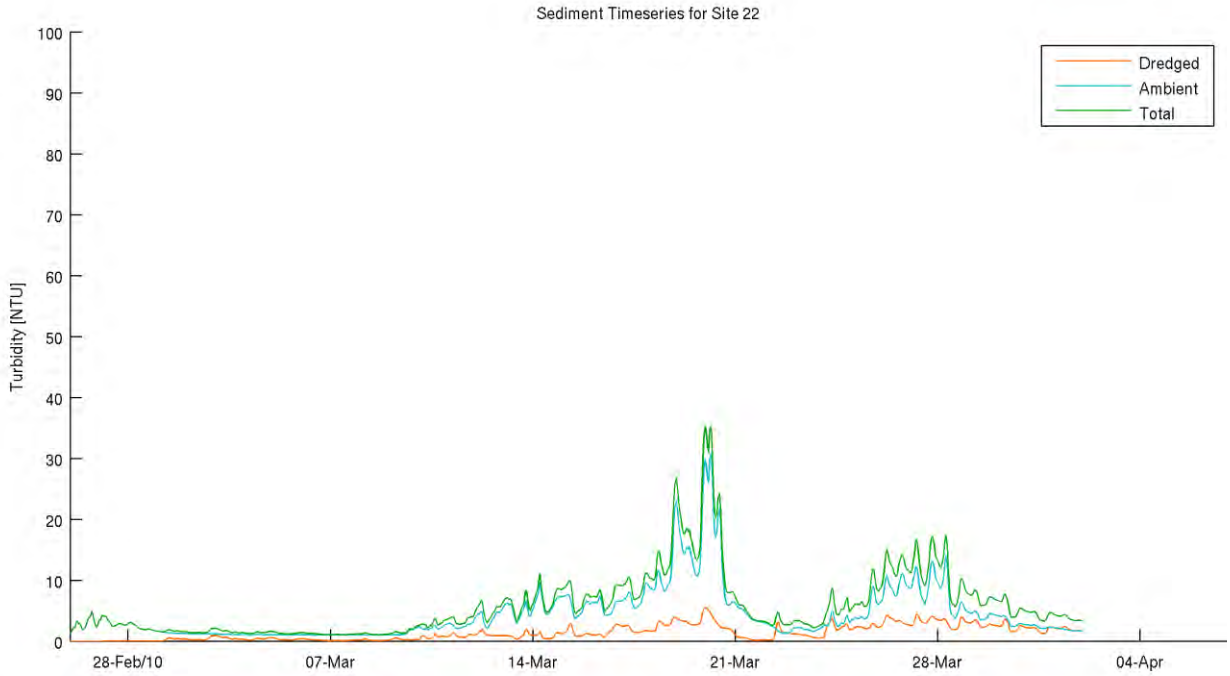
Turbidity Time Series Plots

Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – March 2010 Conditions



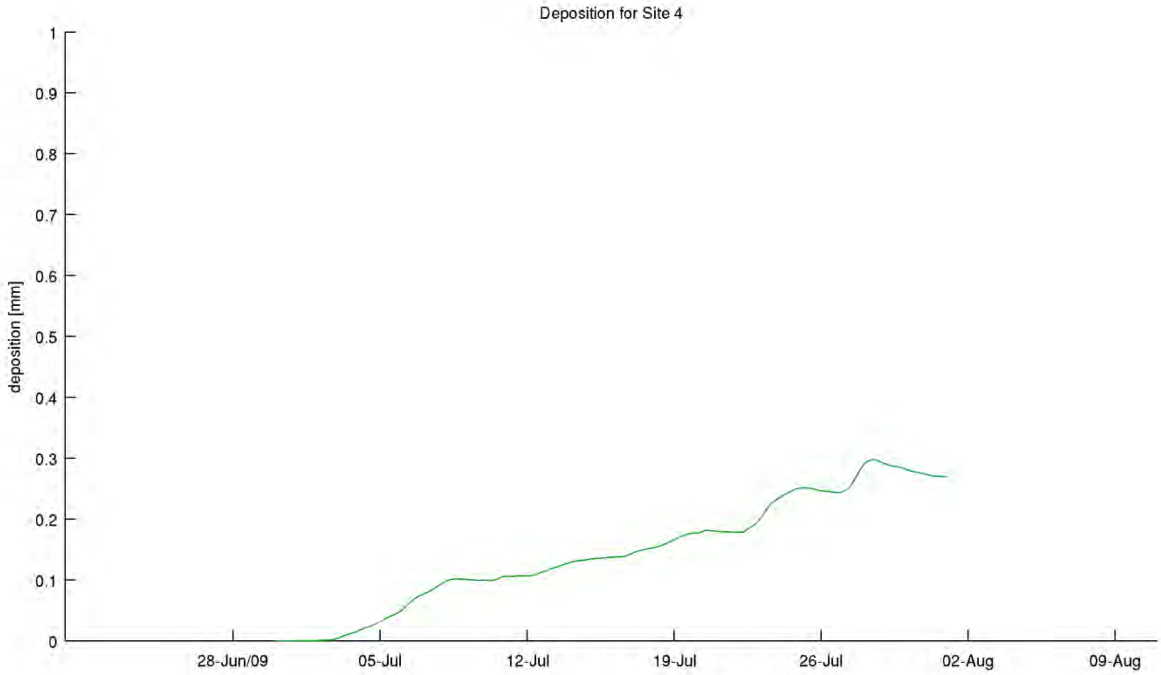


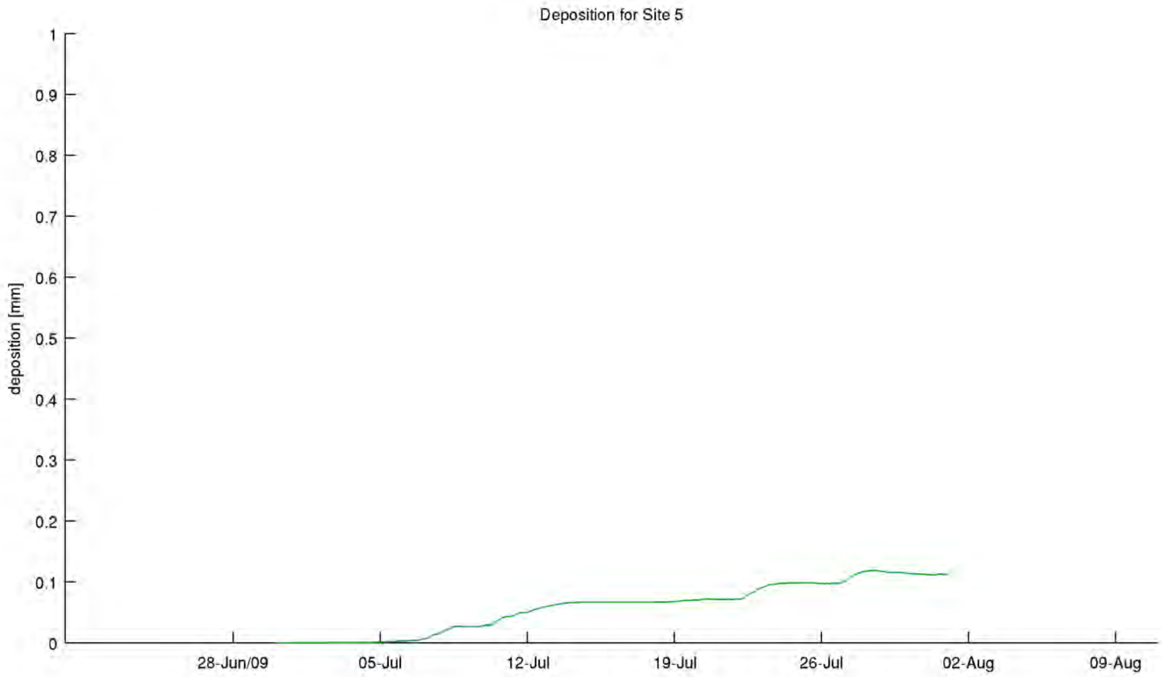

Sediment Timeseries for Site 6
Dredged
Ambient
Total
Turbidity [NTU]
100
90
80
70
60
50
40
30
20
10
0
28-Feb/10
07-Mar
14-Mar
21-Mar
28-Mar
04-Apr


Sediment Timeseries for Site 22
Dredged
Ambient
Total
Turbidity [NTU]
100
90
80
70
60
50
40
30
20
10
0
28-Feb/10
07-Mar
14-Mar
21-Mar
28-Mar
04-Apr

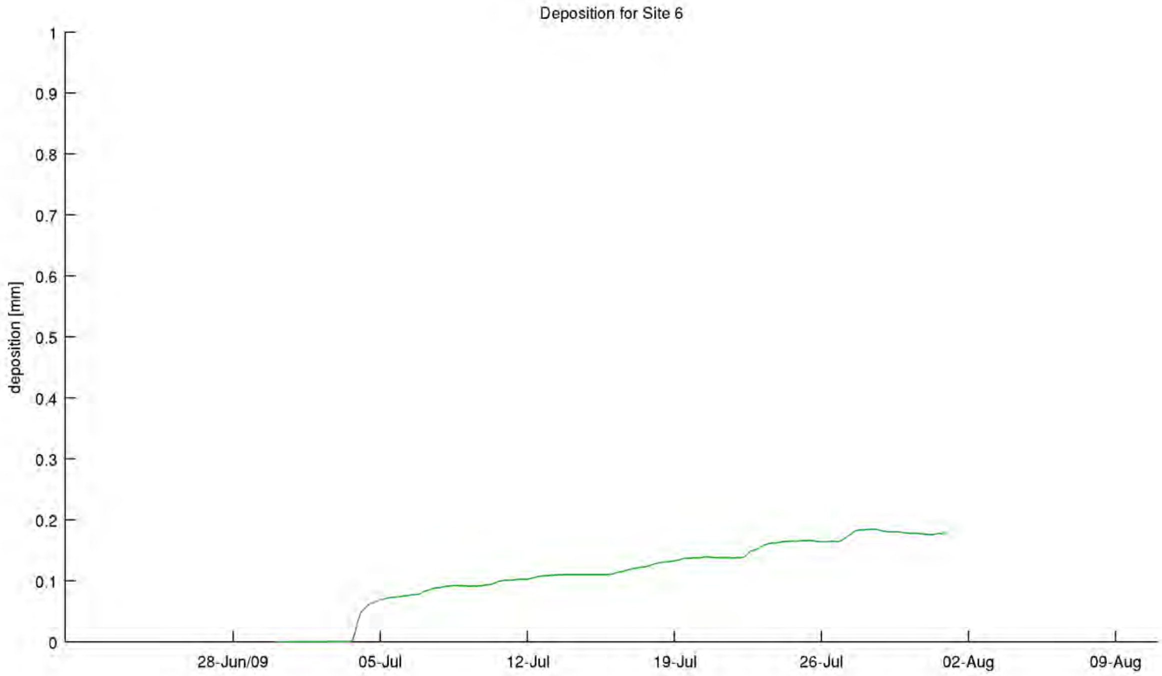
Sediment Deposition Time Series Plots

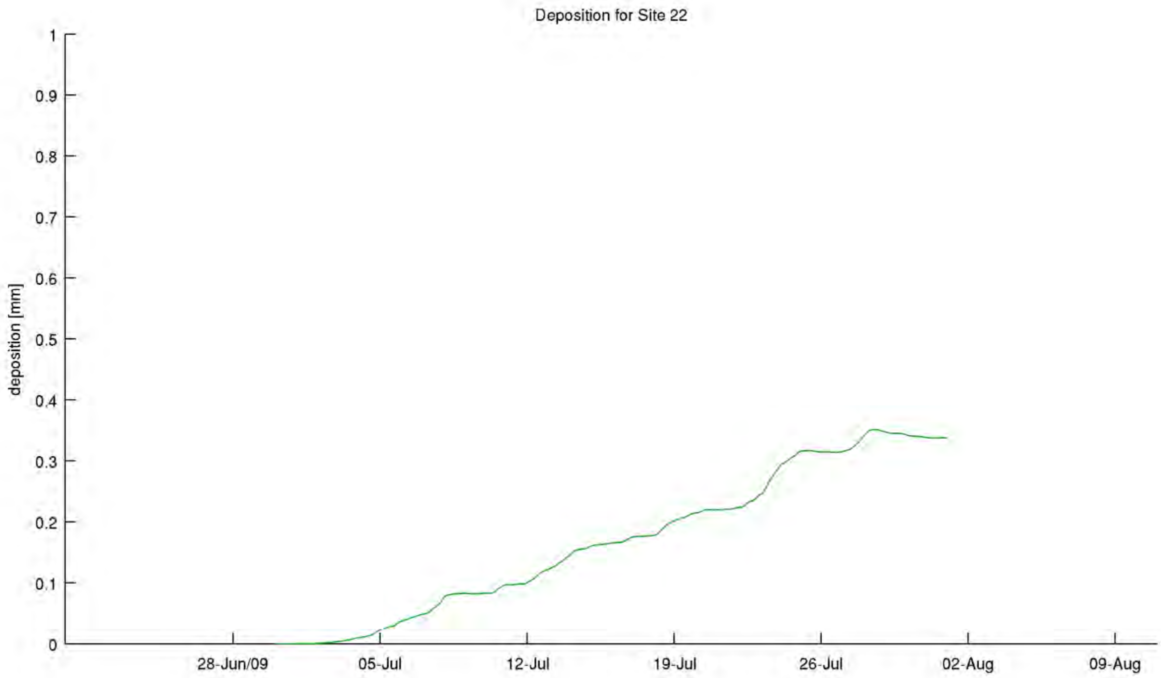
Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – July 2009 Conditions





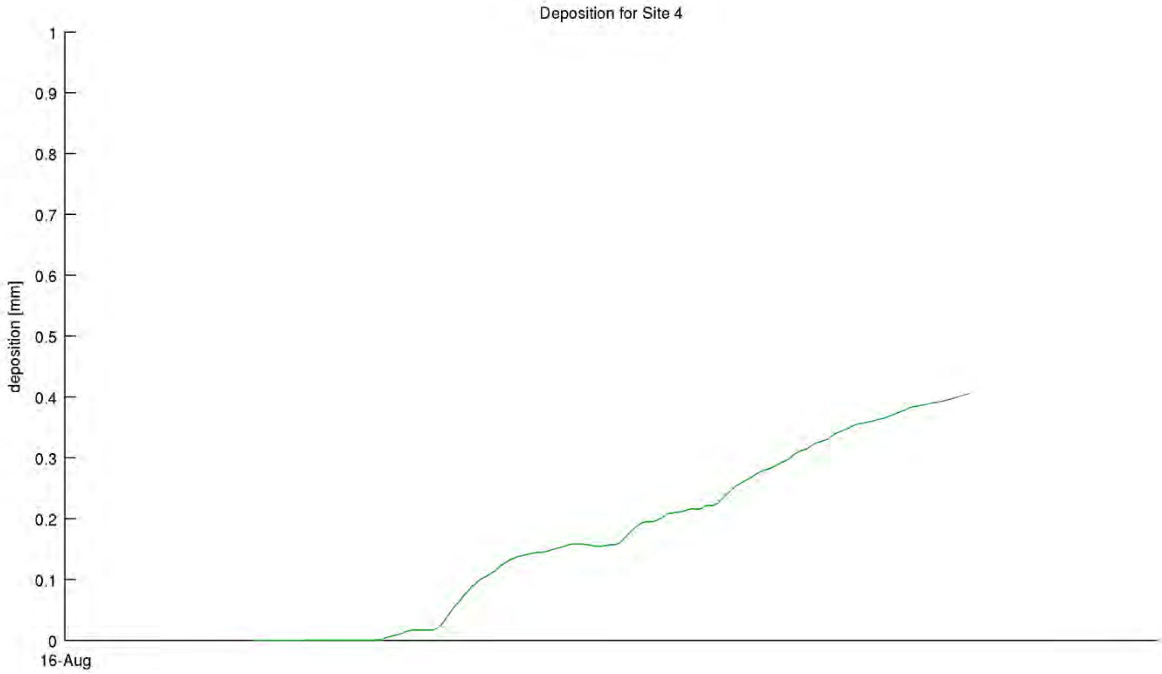
Plume Modelling Time Series Output

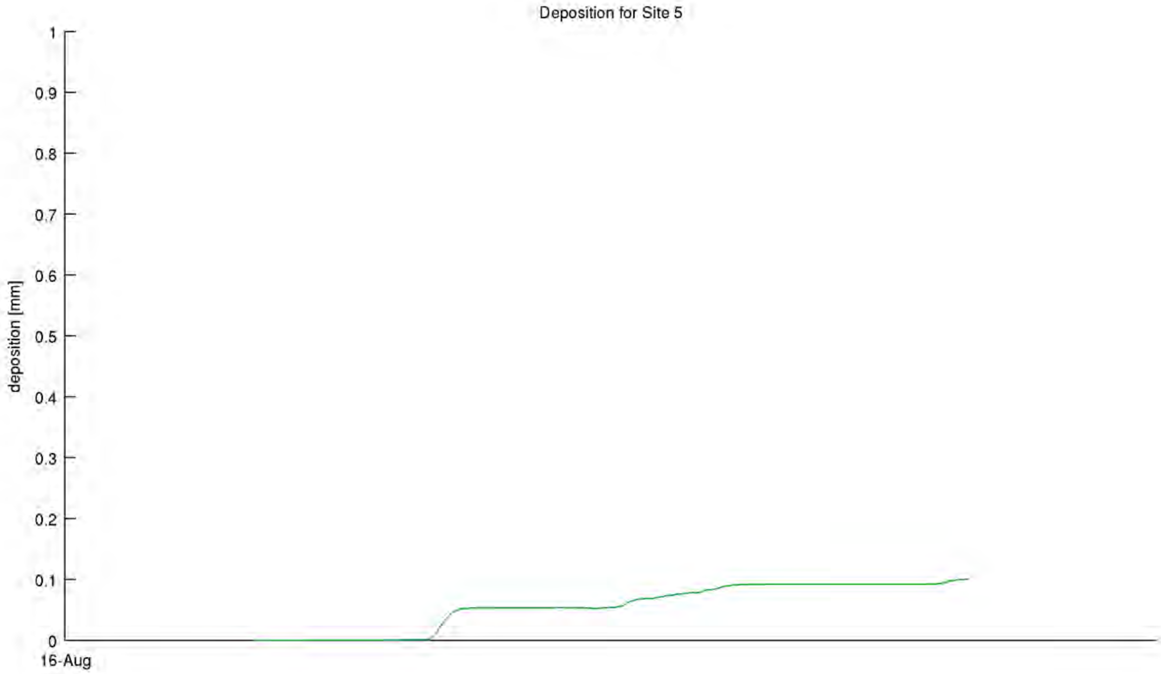




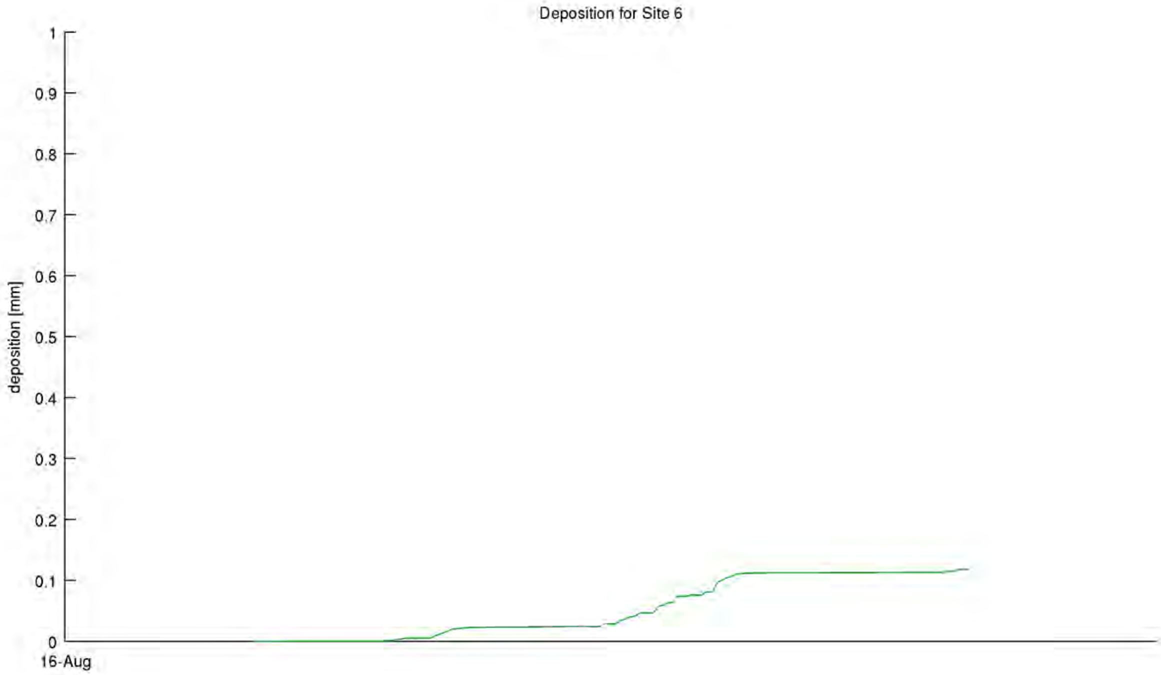
Sediment Deposition Time Series Plots

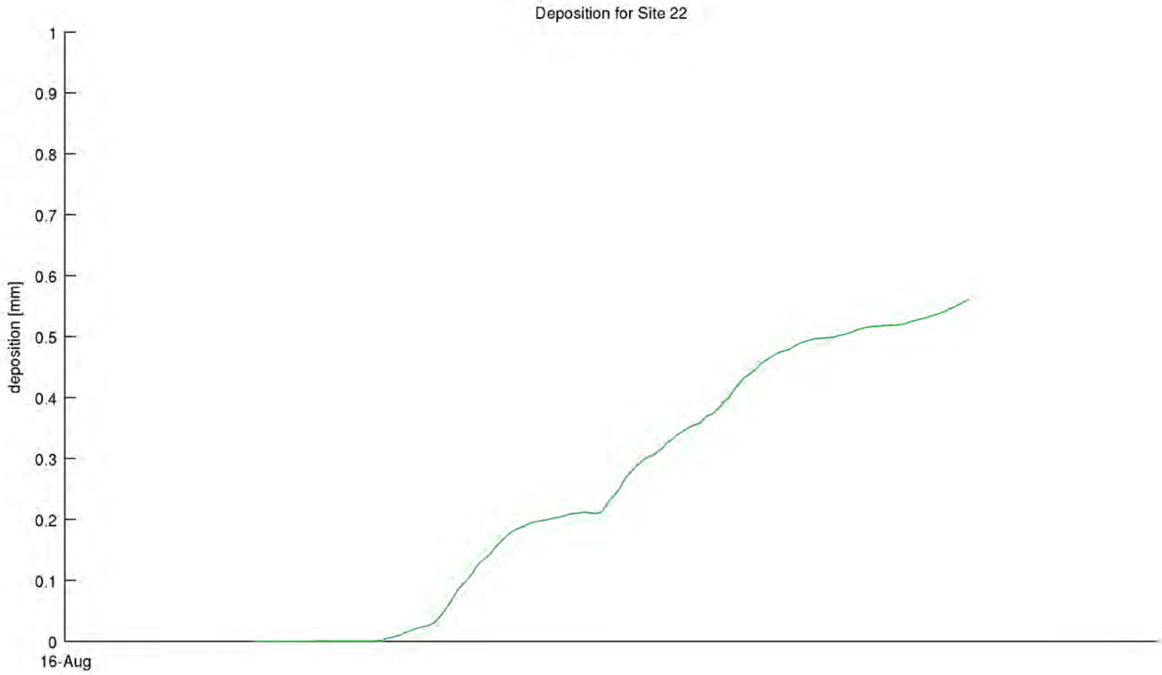
Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – September 2009 Conditions





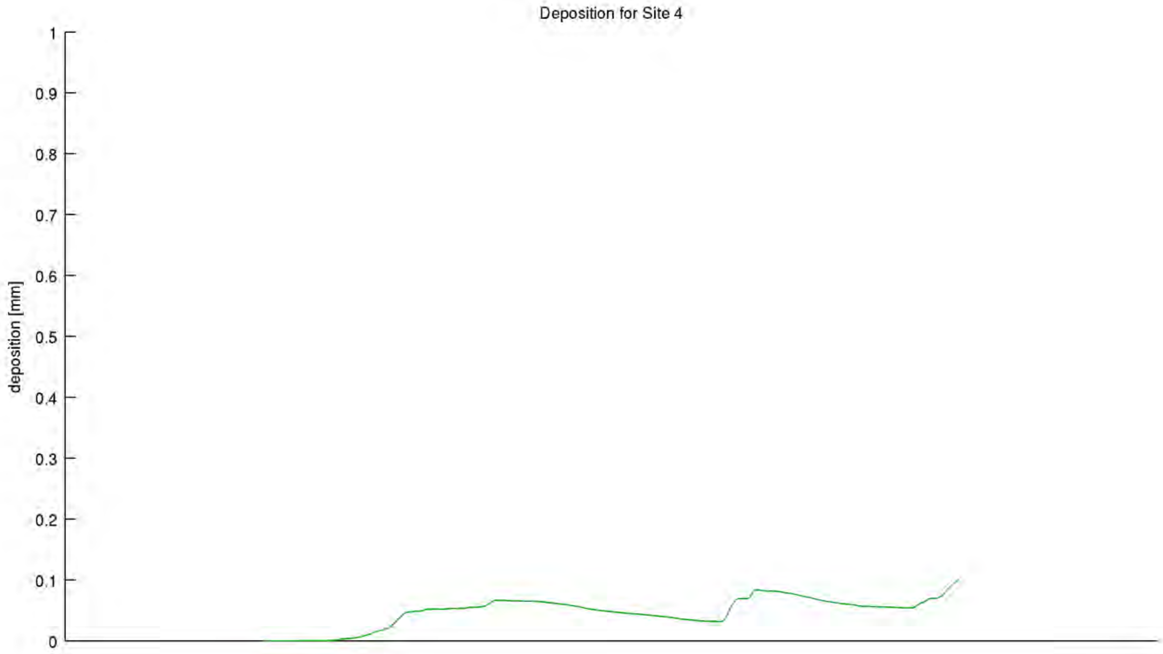
Plume Modelling Time Series Output

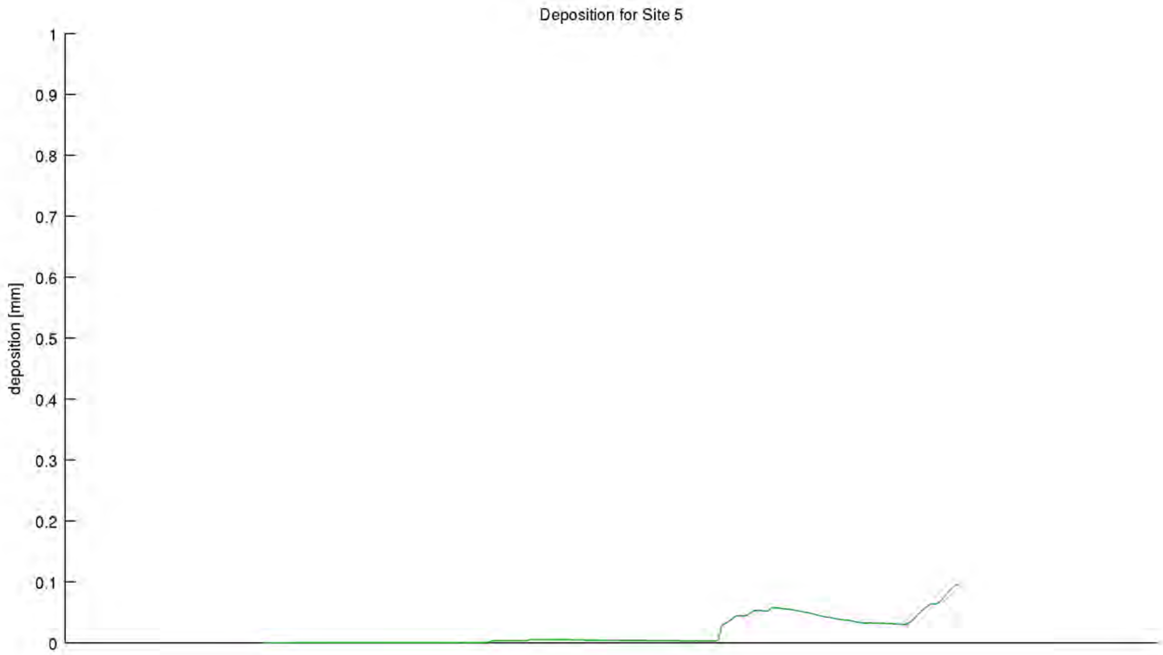


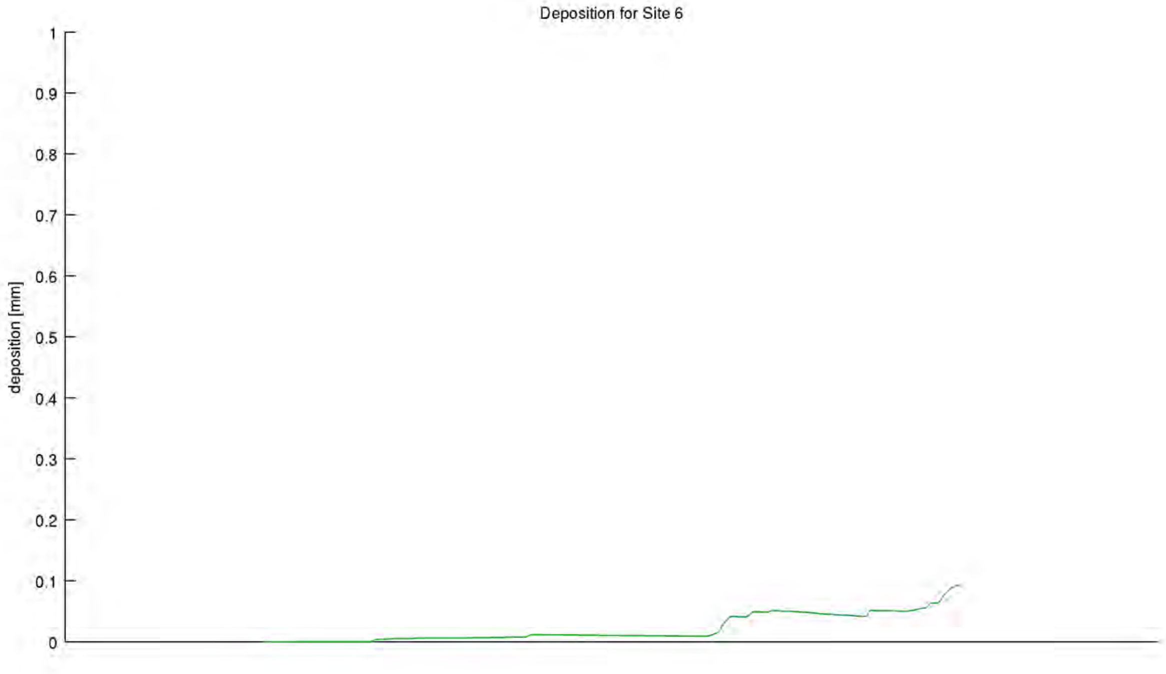


Sediment Deposition Time Series Plots

Stage 3 – Small TSHD Channel Dredging – Dense Clayey Sand Material – March 2010 Conditions






Deposition for Site 6
deposition [mm]
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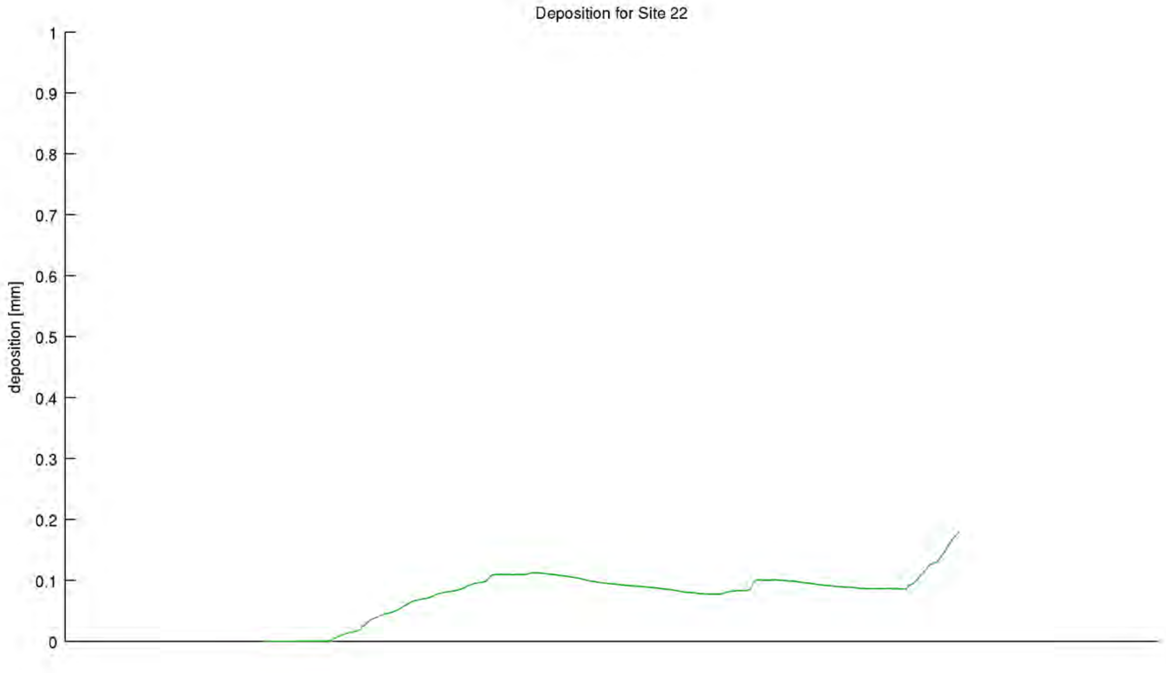
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


Deposition for Site 22
deposition [mm]
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0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

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